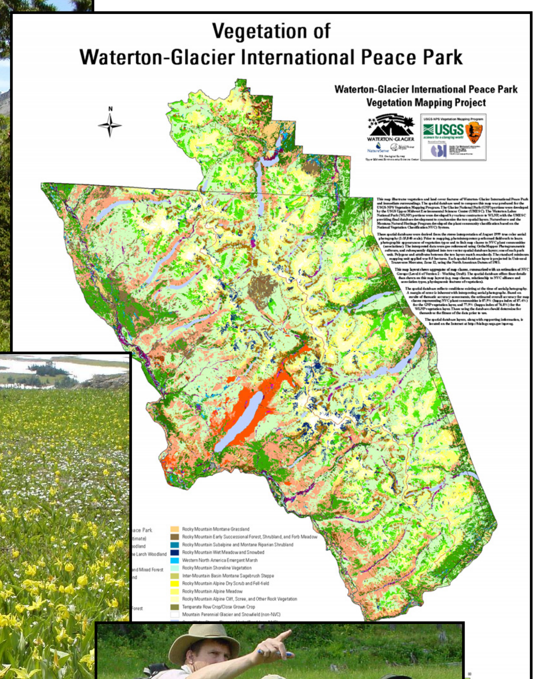
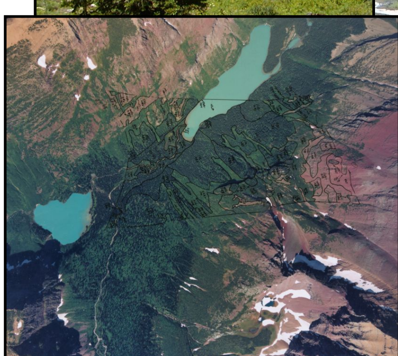
U.S. Geological Survey-National Park Service
Vegetation Mapping Program
Waterton-Glacier International Peace Park

WATERTON·GLACIER

Project Report
August 2007





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U.S. Geological Survey-National Park Service Vegetation Mapping Program Waterton-Glacier International Peace Park

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We respectfully thank the U.S. Geological Survey-National Park Service Vegetation Mapping Program staff for entrusting this project to us, for finding and providing us the funds to sustain the effort, giving us guidance when we needed it, and encouraging us along the way as we rode this *elephant*. We also thank the U.S. Bureau of Reclamation for diligently acquiring the aerial photography we used for the interpretive mapping. Thanks are also in order to the superb staff at Glacier National Park and Waterton Lakes National Park for hosting this project with its series of meetings, training sessions, and field efforts. They provided the project with valuable local knowledge of such a diverse landscape, insight into local management and research needs, kept us current with available data sets, and even participated in hiring folks for various efforts of the project.

We finally thank our colleagues from within our own offices; the U.S. Geological Survey Upper Midwest Environmental Sciences Center, NatureServe, and Montana Natural Heritage Program. Your diligence in working on this colossal project is highly regarded and appreciated as your labors went toward so many aspects of this project—from vegetation classification to spatial database sets for geographic information systems.

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U.S. Geological Survey-National Park Service
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by

Kevin Hop, Marion Reid, Jennifer Dieck, Sara Lubinski, and Stephen Cooper

Summary

The U.S. Geological Survey-National Park Service Vegetation Mapping Program (VMP) is a cooperative effort by the U.S. Geological Survey (USGS) and the National Park Service (NPS) to classify, describe, and map existing vegetation of national park units for the Natural Resource Inventory and Monitoring (I&M) Program. The VMP, managed by the USGS Center for Biological Informatics and the NPS Biological Resources Management Division, provides baseline vegetation information to the NPS I&M Program. The USGS Upper Midwest Environmental Sciences Center, NPS Glacier National Park (GNP), Parks Canada Waterton Lakes National Park (WLNP), NatureServe, and Montana Natural Heritage Program have completed the classification and mapping of plant communities of Waterton-Glacier International Peace Park (IPP) and immediate surroundings.

The Waterton-Glacier IPP classification and mapping effort provides the first opportunity for a joint vegetation classification and map coverage of the two national parks as an international effort. The classification and map products are a valuable data resource to help support a wide variety of management needs for WLNP and GNP, and for the collective Waterton-Glacier IPP.

Photointerpreters, ecologists, and botanists from the United States. and Canada collaborated to describe National Vegetation Classification (NVC) System plant associations (communities) and determine how best to map them using aerial photographs. The team collected 682 vegetation sampling plots within the Waterton-Glacier IPP project extent; 628 from the GNP project area, and 54 from the WLNP project area. Vegetation data from other existing data sets provided an additional 1,100 plots for the vegetation analysis. Furthermore, data from 1,160 accuracy assessment (AA) sites were collected (918 from GNP and 242 from WLNP). These data sets combined led to the identification of 226 NVC plant communities at Waterton-Glacier IPP (198 from vegetation plots, and 28 from AA sites).

Forty-eight map classes were developed to map the vegetation and general land cover of Waterton-Glacier IPP, with 42 of them representing NVC vegetation types. The other six map classes depict general land cover; three representing non-vegetated land cover and three representing developed areas. Two spatial databases were produced to show locations of vegetation and general land cover; one of GNP and environs and one of WLNP and adjoining Blood Indian Timber Limit. Features were interpreted using high-quality stereoscopes over light tables and 1:15,840-scale true color aerial photographs dated August 1999. An additional set of 1:24,000-scale color infrared aerial photos dated August 1997 were used for additional reference. Polygon units were mapped to 0.5 ha (1.25 acres) and, for specific cases, to 0.25 ha

(0.62 acres). The interpreted data were digitally and spatially referenced, making the spatial database layers usable in geographic information systems (GIS).

Collectively, the GNP and WLNP spatial database layers provide nearly 109,833 polygons of detailed attribute data covering 494,842.6 ha (1,222,782.8 acres), with an average polygon size of 4.5 ha (11.1 acres). Of the area mapped, 102,124 polygons (93%) represent NVC vegetation types, encompassing 469,190 ha (1,159,394.3 acres; 94.8%) of the total map extent. The GNP lands account for 82.5% of the entire map extent, with an additional 7.1% for environs around GNP, making up 89.6% of the combined Waterton-Glacier IPP project boundary extent. The WLNP lands account for about 10% of the map extent, with the BITL about 0.4%; the WLNP spatial database makes up 10.4% of the full boundary extent.

Summary reports generated from the spatial database layers indicate forest and woodland types dominating the landscape, populating 55% of the polygons and covering 66.5% of the entire Waterton-Glacier IPP map extent. Two thematic AA studies were conducted of map classes representing NVC plant communities; one on the GNP layer, and the other on the WLNP layer. (Two AA studies were performed independent each other because the GNP and WLNP layers were each mapped by a different mapping group.) Results for the GNP layer present an overall accuracy of 87.9% (Kappa index of 87.4%); based on data from 918 AA field sites. Results for the WLNP layer give an overall accuracy of 77.9% (Kappa index of 76.8%); based on data from 242 AA field sites. Most individual map class themes exceed the VMP standard of 80% with a 90% confidence interval.

The Waterton-Glacier IPP Vegetation Mapping Project delivers many geospatial and vegetation data products in hardcopy and digital formats. These products consist of an in-depth project summary report discussing methods and results, which include plant community descriptions and dichotomous keys, map classification and descriptions, and AA contingency tables. They also include representative ground photos of plant communities, database sets of vegetation plots and AA sites, field data sheets, aerial photograph prints and images, hardcopy maps, and spatial databases of vegetation communities, fieldwork locations, aerial photo indexes, and project boundaries. All geospatial products are in Universal Transverse Mercator projection, Zone 12, using North American Datum of 1983. More VMP information and products of completed park mapping projects are on the Internet at <http://biology.usgs.gov/npsveg>.

Introduction

Waterton-Glacier International Peace Park Vegetation Mapping Project

The Waterton-Glacier International Peace Park (IPP) Vegetation Mapping Project is an initiative of the U.S. Geological Survey (USGS)-National Park Service (NPS) Vegetation Mapping Program (VMP) to classify and map plant communities of Glacier National Park (GNP), with an expanded effort to include Waterton Lakes National Park (WLNP) of Parks Canada (PC). The goals of the project are to adequately describe and map plant communities of Waterton-Glacier IPP and provide the NPS Inventory and Monitoring (I&M) Program, resource managers, and biological researchers with useful baseline vegetation information. The Waterton-Glacier IPP classification and mapping effort provides the first opportunity for a seamless vegetation classification and map coverage for the two national parks. The classification and map products are a valuable data resource to help support not only a wide variety of management needs for WLNP and GNP independently, but also for the Waterton-Glacier IPP as a whole.

We officially inaugurated the mapping project June 1998 with a scoping meeting where partners discussed project objectives, goals, and methods (Figure 1). Major collaborators at this meeting included the VMP coordinating offices (USGS Center for Biological Informatics [CBI] and NPS Natural Resources Information Division [now the Biological Resources Management Division, BRMD]), the NPS GNP, the PC WLNP, The Nature Conservancy (now NatureServe), the Montana Natural Heritage Program, and the USGS Environment Management Technical Center (now the Upper Midwest Environmental Sciences Center).

Figure 1. Park tour during scoping meeting held at Glacier National Park, June 1998.

Common to all VMP projects, the three major components of the Waterton-Glacier IPP Vegetation Mapping Project are (1) vegetation classification, (2) vegetation mapping, and (3) map accuracy assessment. In this report, we discuss each of these fundamental components in detail.

The USGS-NPS Vegetation Mapping Program

The USGS-NPS VMP is a cooperative effort by the USGS and the NPS to classify, describe, and map existing plant communities in national park units across the United States. The VMP, managed by the USGS CBI and the NPS BRMD, provides baseline vegetation information to the NPS I&M Program. Vegetation maps and associated information support a wide variety of resource assessment, park management, and planning needs. They also provide structure for framing and answering critical scientific questions about vegetation communities and their relation to environmental processes across the landscape.

Vegetation Mapping Program scientists developed procedures for classification, mapping, and accuracy assessment (The Nature Conservancy [TNC] and Environmental Systems Research Institute 1994a, 1994b; TNC et al. 1994). Ecology and mapping teams worked together to share knowledge and data and to resolve issues regarding classification and mapping procedures. The VMP products meet Federal Geographic Data Committee (FGDC) standards for vegetation classification and metadata, and meet national standards for spatial accuracy and data transfer. Mapping standards include a minimum mapping unit (MMU) of 0.5 ha (1.2 acres) and classification accuracy meeting or exceeding 80% (with a 90% confidence level) for map classes representing plant communities. All geospatial products are in Universal Transverse Mercator (UTM) projection using North American Datum of 1983 (NAD83).

The VMP provides an array of data products (<http://biology.usgs.gov/npsveg/about.html>). Spatial data products include aerial photographs, map classification, map classification description key, spatial database of vegetation communities, hard-copy maps of vegetation communities, metadata for spatial databases, and an accuracy assessment of the vegetation map. Vegetation information includes vegetation classification, dichotomous field key to the vegetation classes, formal descriptions and ground photos of the vegetation classes, and field data in database format. More VMP information and products of completed park mapping projects are on the Internet at <http://biology.usgs.gov/npsveg>.

Natural Resource Inventory and Monitoring Program

The NPS Natural Resource I&M Program is a long-term effort to acquire information needed to help maintain ecosystem integrity for all national park units with significant natural resources. One of the I&M Program's long-term goal is to produce baseline inventories of basic biological and geophysical natural resources. The VMP provides detailed vegetation maps based on aerial photographs and meets specified thematic accuracy standards (80%) set by the I&M Program. In producing vegetation maps, the VMP also provides a listing of plant species derived from its mapping projects, contributing yet another I&M Program baseline inventory product. More information on the I&M Program is on the Internet at <http://www1.nature.nps.gov/protectingrestoring/IM/inventoryandmonitoring.htm>.

Vegetation Mapping Program Standards

The VMP uses nationally defined standards, some of which are maintained by the FGDC. These include the

- National Vegetation Classification Standard (FGDC 1997),
- Content Standard for Digital Geospatial Metadata (FGDC 1998a),
- Spatial Data Transfer Standard (FGDC 1998b),
- United States National Map Accuracy Standards (U.S. Geological Survey 1999), and
- Integrated Taxonomic Information System (U.S. Department of Agriculture).

Descriptions and links to websites for these standards can be accessed on the VMP website (<http://biology.usgs.gov/npsveg/standards.html>).

The National Vegetation Classification Standard

In 1997, the FGDC adopted the Vegetation Classification Standard: FGDC-STD-005-1997 (FGDC 1997). The purpose of the classification standard is to ensure consistent classification of vegetation resources across regions. The use of a standardized national vegetation classification system aids effective resource stewardship by ensuring compatibility and helps widespread use of the information throughout the NPS and other Federal and state agencies.

The National Vegetation Classification Standard is hierarchical with five physiognomic levels and two floristic levels (Table 1, Grossman et al. 1998). Key attributes of the classification standard are (1) based on existing vegetation, (2) applied to natural resources, and (3) a hierarchical system defined by physiognomy and floristics (Faber-Langendoen 2001). The classification is based on the United Nations Educational, Cultural, and Scientific Organization (UNESCO) world physiognomic classification of vegetation (UNESCO 1973), which was modified to provide greater consistency at all hierarchical levels and include additional types, thus setting up the framework for the upper physiognomic levels (Grossman et al. 1998, Drake and Faber-Langendoen 1997). The lower floristic levels are devised from a national framework developed by TNC (and now maintained and revised by NatureServe) and their network of state heritage programs for more than 20 years (Grossman et al. 1998). The physiognomic-floristic classification includes all rooted vascular plants.

Table 1. National Vegetation Classification Standard physiognomic-floristic hierarchy for terrestrial vegetation.

Level	Primary Basis For Classification	Example
Class	Growth form and structure of vegetation	Woodland
Subclass	Growth form characteristics (e.g., leaf phenology)	Deciduous woodland
Group	Leaf types, corresponding to climate	Cold-deciduous woodland
Subgroup	Relative human impact (natural/semi-natural or cultural)	Natural/semi-natural
Formation	Additional physiognomic and environmental factors, including hydrology	Temporarily flooded cold-deciduous woodland
Alliance	Dominant/diagnostic species of uppermost or dominant stratum	*Populus deltoides* temporarily flooded woodland alliance
Association	Additional dominant/diagnostic species from any strata	*Populus deltoides* - (*Salix amygdaloides*) / *Salix exigua* woodland

The coarsest physiognomic level of the classification is “class” and categorizes vegetation on its most basic physiognomic structure (e.g., forest, woodland, shrubland). The finest physiognomic level is “formation” and categorizes vegetation by dominance of a given growth form in the uppermost stratum and characteristics of the environment (e.g., cold-deciduous alluvial forests).

The two floristic levels are alliance and association and are the two finest levels of the classification standard. These levels are based on species composition (Maybury 1999) and are developed from dominant or diagnostic species rather than physiognomic patterns of dominant species (Grossman et al. 1998). Faber-Langendoen (2001) explains dominant species as plant species of predominance in a community because of its size, abundance, or coverage. In addition, characteristic (diagnostic) species, in contrast, are plant species commonly found in a particular community and are used in the delimitation of that community. An alliance type has been described as a group of physiognomically uniform plant associations sharing dominant or diagnostic species, usually in the uppermost strata of the vegetation (see Mueller-Dombois and Ellenberg 1974 as cited in Drake and Faber-Langendoen 1997), e.g., *ABIES*

LASIOCARPA - *PICEA ENGELMANNII* FOREST ALLIANCE. The association is the finest level in the classification and has been defined as "a plant community of definite floristic composition, uniform habitat conditions, and uniform physiognomy" (see Flahault and Schroter 1910 in Morovac 1993 as cited in Drake and Faber-Langendoen 1997), e.g., *Abies lasiocarpa* - *Picea engelmannii* / *Acer glabrum* Forest. Most schools of floristic classification have used this concept. The classification standard is hereafter referred to as the National Vegetation Classification (NVC).

Noteworthy, the NVC is undergoing a major revision by the FGDC Vegetation Subcommittee, including adjustments to the classification hierarchical structure. The revision is an effort to foster a cohesive view between federal agencies in their approach to classifying vegetation, thus reducing duplicative efforts among multiple agencies. The revised NVC version will replace the 1997 version and is expected to be complete and ready for public use late 2007.

Content Standard for Digital Geospatial Metadata

Metadata are data about data and describes the content, quality, condition, and other characteristics of data. As a standard product, the VMP employs FGDC compliant metadata files for each spatial data set it produces. In 1998, the FGDC approved the Content Standard for Digital Geospatial Metadata: FGDC-STD-001-1998 (FGDC 1998a). This metadata standard uses a common set of terminology and definitions to document digital geospatial data. For spatial data sets involving biological components, the VMP uses the FGDC endorsed Biological Data Profile (a profile is a set of information specific to a discipline, in this instance the biological sciences discipline), which is a biological metadata standard developed by the National Biological Information Infrastructure. This is known as the Biological Data Profile of the Content Standard for Digital Geospatial Metadata: FGDC-STD-001.1-1999 (FGDC 1999).

Waterton-Glacier International Peace Park

Location and History

Waterton-Glacier International Peace Park

The Waterton-Glacier IPP is located in southwest Alberta, Canada and northwest Montana, United States (Figures 2 and 3). The Rocky Mountains and the Continental Divide (CD) traverse the Waterton-Glacier IPP north to south. The entire Waterton-Glacier IPP comprises an area of approximately 458,556 ha (1,133,116 acres), and shares approximately 30.5 km (19 miles) of the Canada-United States International Boundary (on the 49^{th} parallel).

The Waterton-Glacier IPP became the world's first International Peace Park in 1932 when WLNP (Alberta, Canada) was combined with GNP (Montana, United States). The combination of these parks began through local government efforts when international cooperation between Rotary Club members from both Alberta and Montana petitioned Canada and the United States to unite the two national parks. The Waterton-Glacier IPP serves as a symbol of longtime friendship between the two nations, and commemorates the bonds of peace. It also emphasizes the cooperation needed between the two national parks for stewardship of adjoining natural resources.

Figure 2. Location of Waterton-Glacier International Peace Park.

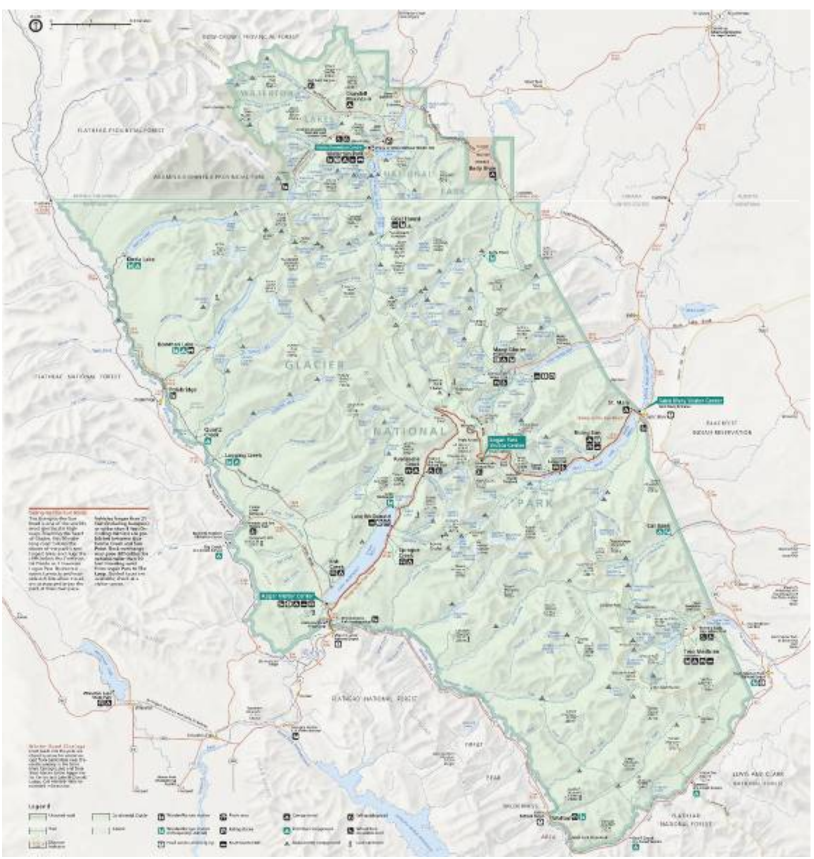

Figure 3. Park map of Waterton-Glacier International Peace Park.

With the Waterton-Glacier IPP situated on the international border, plants and animals essentially take no notice of political boundaries (Figure 4). Although GNP and WLNP are administered by separate countries, the IPP offers an avenue to cooperate in their management of natural and cultural resources.

In late 1995, the Waterton-Glacier IPP was designated by the UNESCO as a World Heritage Site for its scenery and wealth of plant and animal species (accessed 12/12/2006 <www.pc.gc.ca/pn-np/ab/waterton/natcul/inter_E.asp>). The UNESCO also declared both national parks as Biosphere Reserves; the GNP in 1976, and the WLNP three years later in 1979.

Figure 4. Boundary marker at the Canada-United States International border.

Waterton Lakes National Park - Parks Canada

Waterton Lakes National Park (Figure 5) is one of more than 40 national parks operated by PC. It is Canada's fourth national park, established in 1895. The park was named after the chain of Waterton Lakes. Waterton Lakes National Park is located in the far southwest corner of Alberta, Canada, along the Canada-United States International border. Directly to the south and across the international border is GNP in Montana. The park's western boundary is defined by the CD, which is also the border to the Province of British Columbia. These lands are the Akamina-Kishinena Provincial Park and the Flathead Provincial Forest. The park's eastern and northern sides are bordered by the Bow-Crow Forest, Blood Indian Timber Limit (BITL), and private lands. Waterton Lakes National Park is 270 km (168 miles) south of Calgary, Alberta, and 130 km (81 miles) southwest of Lethbridge, Alberta.

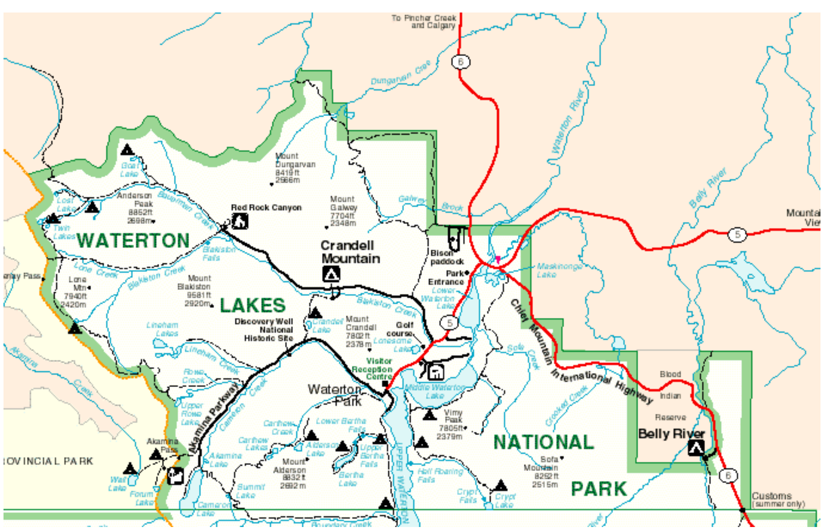

Figure 5. Waterton Lakes National Park, Alberta, Canada.

Today, WLNP comprises an area of about 50,500 ha (124,788 acres). Significant landmarks include the townsite of Waterton Park, the chain of three lakes, which the park is named after (Upper Waterton Lake, Middle Waterton Lake, and Lower Waterton Lake), Cameron Lake, the Prince of Wales Hotel National Historic Site, the Lineham Discovery Well National Historic Site, and Mount Blakiston, which is the park's highest mountain peak with an elevation of 2,920 m (9,580 ft). Mount Blakiston is approximately 1,641 m (5,384 ft) above the Waterton Lakes. The lowest elevation in WLNP is approximately 1,234 m (4,050 ft) where the Waterton River exits the park to the north.

Glacier National Park - U.S. National Park Service

Glacier National Park (Figure 6) is one of more than 270 park units of the NPS. It is the United States 10th national park, established in 1910. The park was first designated as a Forest Preserve in 1900. Glacier National Park is located in northwest Montana along the Canada-United States International Border. Directly to the north and across the international border is WLNP in Alberta (east of the CD), and the Flathead Provincial Forest and Akamina-Kishinena Provincial Park in British Columbia (west of the CD). Bordering most of the park's eastern boundary is the Blackfeet Indian Reservation, and bordering most of the park's western and southern boundary is the Lewis and Clark National Forest and the Flathead National Forest. Glacier National Park provides the headwaters to three major watersheds: Pacific Ocean, Hudson Bay, and Gulf of Mexico. Glacier National Park is 50 km (31 miles) northeast of Kalispell, Montana.

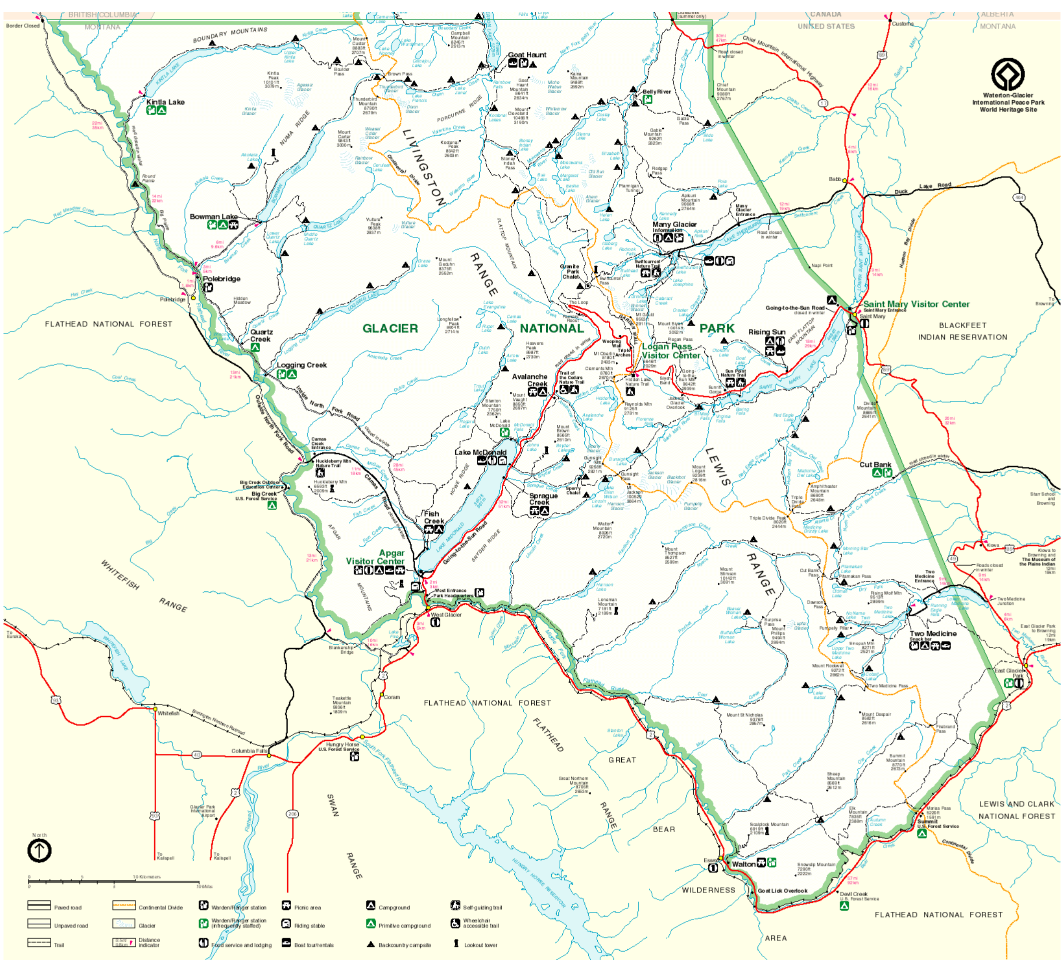

Figure 6. Map of Glacier National Park, Montana, United States.

Today, GNP comprises an area of nearly 408,056 ha (1,008,328 acres). Significant landmarks include the Going-to-the-Sun Road (National Historic Civil Engineering Landmark and National Register of Historic Places), Logan Pass, five historic chalets and hotels listed on the National Historic Landmarks, several large glacial-formed lakes (Lake McDonald and Saint Mary Lake being the largest and more popular), and numerous mountain peaks exceeding 3,000 m (9,843 ft). Mount Cleveland is the park's highest peak, reaching 3,190 m (10,466 ft) at the summit. The lowest elevation in GNP is approximately 950 m (3,116 ft) where the Middle and North Forks of the Flathead River meet just as the river leaves the park to the south near the Blankenship Bridge.

Natural Resources

The Waterton-Glacier IPP protects an important mosaic of ecosystems where the Rocky Mountains reach their narrowest width. It is at this park where a convergence of several ecosystems occurs, including the Northern Rocky Mountains meeting the Central Rocky Mountains, and the Great Plains from the east meeting the Maritime of the Pacific Northwest from the west. With elements of prairie, montane, alpine, and maritime ecosystems converging at Waterton-Glacier IPP, the natural resources are highly diverse both physically and biologically.

The area Waterton-Glacier IPP falls within is aptly known at the Crown of the Continent, and offers impressive scenery rich in both plant and animal species (Figure 7). Both WLNP and GNP were designated as a national park by their respective nations because of their mountain scenery and rugged terrain, glacial landforms, and abundance of wildlife and wildflowers.

Glaciers have contributed to the diverse physical and biological nature of the Waterton-Glacier IPP. Glacial activity has eroded mountains into peaks and ridges (e.g., Gunsight Mountain), formed steep-sided cirques often complemented with subalpine lakes (e.g., Iceberg Lake), carved broad-bottomed steep-sided U-shaped valleys often complemented with deep elongated lakes (e.g., Upper Waterton Lake, Lake Mc Donald), and deposited glacial moraine and gravel ridges (eskers) from glacial mobility and streambeds. Glaciers have fashioned a pristine beauty in the landscape of Waterton-Glacier IPP, and also have made for a sundry landscape for a diversity of plants and animals to live in (Figure 8).

Figure 7. Plant and animal diversity at Crown of the Continent.

Figure 8. Diverse landscape carved by glacial activity.

Wind and fire have also played an important role in the natural setting at Waterton-Glacier IPP. Wind has a prominent effect on the physiognomic structure of vegetation, either the growth pattern (Figure 9) on the landscape or the actual physiognomic shape of the plant itself (Figure 10). Likewise, fire has dramatically pushed back forest succession, revitalizing vegetation diversity and directly affecting wildlife use.

Figure 9. Wind-swept patterning of *Dryas octopetala*.

Figure 10. Wind-swept branching of krummholz *Abies lasiocarpa*.

Previous Vegetation Studies

Although neither is in close proximity to a population center, both GNP and WLNP are quite accessible. This, combined with highly diverse and relatively unspoiled ecosystems, has resulted in a multitude of scientific investigations, including flora and vegetation. Lesica's (2002) and Kuijt's (1982) manuals of GNP and WLNP vascular floras, respectively, are products of decades of dedicated field inventory and provide concise descriptions and habitat notes regarding local conditions, making them particularly useful in appreciating the vegetation (see the excellent lifezone discussion in Lesica 2002). Although somewhat dated, studies also exist for lichens (DeBolt and McCune 1993) and bryophytes (Hermann 1969) in GNP. In addition, Hansen (1948) employed palynology to describe vegetation from a historic perspective, explaining forest changes post-Pleistocene and Carrara (1989) provided a vegetation history attuned to glacial movement. The most authoritative source of vegetation description for GNP is Habeck's (1970) "Vegetation of Glacier National Park, Montana" and for WLNP, "Ecological Land Classification of Waterton Lakes National Park, Alberta" by Achuff et al. (2002a). The WLNP report by Achuff et al. (2002a) is conveniently organized by ecoregions and structural types and also describes vegetation types at their finest level of the classification, which is analogous to—and many have served as templates for—plant associations we describe within this project. Furthermore, the alpine zone has attracted a number of investigators. The pre-eminent study is Damm's (2001), offering a fine-scale phytosociological classification in the manner of Braun-Blanquet, which encompasses both vasculars and cryptogams. Many of Damm's plant communities were used as nuclei for the more comprehensive plant associations of this study. Although limited in extent, the grasslands of the North Fork Flathead River have been documented both in composition and interaction with fire (Koterba and Habeck 1971), and GNP recently conducted a thorough inventory of montane grasslands east of the CD (Shea et al., unpublished data, 2004).

Three major disturbances having strong influences on vegetation structure and composition at Waterton-Glacier IPP are snow avalanche, fire, and forest pathogen. Butler (1979, 1985) has described the interaction of snow avalanche path terrain and the effects on vegetation structure. Habeck—a fire ecologist at the University of Montana—and various collaborators describe influences of fire and post-fire succession pattern in cedar-hemlock forests (Habeck 1968), ponderosa pine forests (Lunan and Habeck 1973), grasslands (Koterba and Habeck 1971), and other habitats (Habeck and Choate 1963). More recently, Barrett (1993, 1997) and collaborators (Barrett et al. 1991) have documented fire history and fire regimes leading to the present stand structure and tree composition of GNP east of the CD. Kessel (1977) used the Lake McDonald drainage as a test site for employing "gradient modeling," an attempt at predicting fire consequences to landscapes of various environmental gradients, terrain, and vegetation.

Although many forest pathogens exist, four are particularly obvious in their effects on vegetation: (1) tent caterpillars, which can completely defoliate entire stands of trembling aspen (*Populus tremuloides*) and lead to individual tree mortality, (2) white pine blister rust (*Cronartium rubicola*), which has been around for decades, attacking and causing mortality of any five-needle pine (Figure 11), (3) mountain pine beetles (*Dendroctonus ponderosae),* which cause high rates of mortality primarily of lodgepole pine (*Pinus contorta*) (Figure 12), but also of whitebark pine (*P. albicaulis*), and (4) spruce budworm, which causes appreciable mortality in Engelmann spruce (*Picea engelmannii*) and its hybrids. Of these pathogens, white pine blister rust is by far the most consequential, threatening the future survival of whitebark pine ecosystems at Waterton-Glacier IPP. A bear biologist at GNP, in addition to developing a significant vegetation database pertaining to whitebark pine and its habitat, has written authoritatively on the effects of this species' precipitous decline on vegetation and biodiversity (Kendall and Keane 2001; Kendall and Arno 1990; Tomback and Kendall 2001).

Figure 11. High mortality of five-needle pine

Figure 12. High mortality of lodgepole pine

Anthropogenic influences have been intensive, but limited in extent (e.g., local conversion of native prairie or meadows to alien pasture grasses). Now, however, weed populations are becoming broadly distributed and will constitute a distinct threat to native vegetation (Tyser and Key 1988; Tyser and Worley 1992; unpublished data, Shea et al. 2004).

Project Overview

General Process

The three main components of the Waterton-Glacier International Peace Park (IPP) Vegetation Mapping Project are (1) vegetation classification, (2) vegetation mapping, and (3) map accuracy assessment (AA). Our objectives were to identify and map existing vegetation communities of Waterton-Glacier IPP. Accomplishing these goals took several years, given this project was a collaborative effort amongst various agencies (including international agencies), limited funding existed early on in the project (1999 and 2000), the study area was large in size, and a substantial amount of complexity existed in regards to the natural landscape, vegetation, and fire occurrence. Table 2 shows the timeline of activities throughout the entire classification and mapping effort.

Before formally beginning the project, the U.S. Geological Survey (USGS)-National Park Service (NPS) Vegetation Mapping Program (VMP) acquired a set of aerial photographs of Glacier National Park (GNP) and environs—color infrared (CIR) dated August 1997 at a nominal scale of 1:24,000—giving us aerial photographs in hand for the following year's scoping meeting and field reconnaissance. Prior to the scoping meeting, a conference call was held between prospective players to begin formalizing the project. The project was officially inaugurated June 1998 with a scoping meeting at GNP headquarters in West Glacier, Montana. At this meeting, primary partners came together to discuss and plan the project. (The scoping meeting is discussed in more detail later in this section.)

In August 1998, the VMP collected additional CIR aerial photographs of GNP to fill photo holidays—gaps in the aerial photo coverage—from the 1997 photo mission and to retake some frames that were either overexposed from glacier/snow reflectance or obstructed with shadows from clouds.

In September 1998, mappers and classifiers, along with GNP staff, explored vegetation communities east of the Continental Divide (CD) (Figure 13). Local soil and fire experts accompanied, giving insight of how vegetation responds to soil layers and fire occurrence. During this field reconnaissance, we viewed firsthand plant communities and began thinking of vegetation sampling strategies. We also gained a first-look of how plant communities appear on the CIR aerial photographs and began a first draft of the map classification and mapping conventions. It was determined from this field effort that the existing CIR photo set demonstrated viewing limitations of several vegetation types (e.g., similar appearances between tree species, such lodgepole pine and Douglas-fir, made map class assignment challenging), and another set of aerial photographs was needed to compliment the existing CIR set. Thus, a full set of true color (TC) aerial photographs was collected in August 1999 for both GNP and Waterton Lakes National Park (WLNP) with a nominal scale of 1:15,840. (1997 CIR aerial photographs were not acquired for WLNP.)

Figure 13. First reconnaissance of vegetation types at Glacier National Park, September 1998.

Table 2. Timeline of activities for the Waterton-Glacier International Peace Park Vegetation Mapping Project.

Summer 1997	Fall 1997	Winter 1997-98	Spring 1998	Summer 1998	Fall 1998	Winter 1998-99	Spring 1999	Summer 1999	Fall 1999	Winter 1999-2000	Spring 2000	Summer 2000	Fall 2000	Winter 2000-01	Spring 2001	Summer 2001	Fall 2001	Winter 2001-02	Spring 2002	Summer 2002	Fall 2002	Winter 2002-03	Spring 2003	Summer 2003	Fall 2003	Winter 2003-04	Spring 2004	Summer 2004	Fall 2004	Winter 2004-05	Spring 2005	Summer 2005	Fall 2005	Winter 2005-06	Spring 2006	Summer 2006	Fall 2006	Winter 2006-07	Spring 2007	Summer 2007
GNP CIR Photos																																									
		Cnf Call																																					
			Scope Mtg																																				
				GNP CIR Retakes																																			
				E GNP Rcn																																			
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								E GNP VP																															
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																																GNP AA III							
																																WLNP AA							
																																	GNP Phase IV Map						
																																					AA Anlys			
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																																						Wrap-up		
																																								WU Mtg

AA=Accuracy Assessment	CIR=Color Infrared	Dbase=Database Entry	DIG=Digital Mapping	Fld=Field	GT=Ground Truth	ORTHO=Orthomapper	Prelim=Preliminary	TC=True Color	VP=Veg Plots	Wkshp=Workshop
Anlys=Analysis	Cnf=Conference	Dft=Draft	E=East of CD	GNP=Glacier NP	Mtg=Meeting	PI=Photointerpretation	Rcn=Reconnaissance	Veg=Vegetation	W=West of CD	WLNP=Waterton Lakes NP

A planning meeting was held at the Upper Midwest Environmental Sciences Center (UMESC) in December 1998 to strategize the vegetation plot sampling effort (including an environmental stratification scheme), define the project boundary, and determine tasks and schedule for the coming years of plot sampling and mapping.

We collected vegetation plot samples for analyses and documentation of plant communities. Vegetation sampling began in summer 1999 at GNP east of the CD and at WLNP. Training for plot sampling was conducted at GNP prior to the field sampling effort. Sampling concluded in 1999 for WLNP, and continued through 2002 for GNP, initially focusing work east of the CD and then concluding west of the CD. The vegetation data were entered into the PLOTS Database System (TNC 1997) to subsequently be analyzed for classification. The analyses of the plot data, along with other existing vegetation data sets, provided us with detailed information to affirm plant communities of Waterton-Glacier IPP and to draft descriptions describing local characteristics of those communities. We completed a polished version of the vegetation classification, with descriptions and key in 2004 (Reid et al. 2004). The classification was later modified with information and data from additional field work during our map reconnaissance and from the vast collection of AA data.

Simultaneous to vegetation plot sampling, ground truthing for mapping purposes also began in summer 1999 of WLNP and GNP east of the CD. Ground truthing is an important step for mapping, providing opportunity to learn the vegetation as it appears on the aerial photographs. Ground truthing continued for GNP in summers 2000–04, with efforts first prioritized east of the CD and then west of the CD (with the exception of 2003, where extensive fires west of the CD prevented our effort). Ground truthing for WLNP continued through summer 2000.

Sufficient funding allowed the mapping of GNP to commence late 2001 when additional mappers were hired. The mapping field efforts for GNP prior to 2001 established a preliminary working map classification and strengthened the understanding of "theoretical" vegetation classification concepts to apply in mapping. This process of having a complete understanding of the plant communities before mapping is preferred. However, since the vegetation plot sampling work was still being collected and the vegetation analyses was yet to be completed, the mapping effort began without the plant community descriptions in hand. Therefore, as vegetation concepts became known, they were applied to the ongoing mapping effort. When adjustments could be consistently made using a geographic information system (GIS), these vegetation concepts were also applied to those areas already mapped. Photointerpretation and digital map automation continued into early 2007.

Collection of AA observation data (for validating the vegetation map) spanned over three summer field seasons for GNP, starting in 2003 and ending in 2005. The WLNP data collection occurred during 2005. Field crews visited randomly selected sites and identified the plant communities for later comparison to the vegetation map. A cost-surface map was derived to reduce accessibility barriers due to elevation gradients and prolonged distance from camps and roads. Recent fires west of the CD in GNP (those occurring post date aerial photos) provided additional challenges to the random stratification approach. A burn-severity map was added to the mix to eliminate those recent and severely burned areas from the site selection, where fires had occurred subsequent to the aerial photography used in the mapping process. Prior to each year's field season, field crews were trained in collecting AA observation plot data. During winter 2006-07, we evaluated both WLNP and GNP vegetation maps for accuracy using the field data and tabulated the results into a contingency matrix. Per VMP protocol, only map classes representing plant communities are included in the AA.

Throughout the project, various partners collaborated via e-mail and phone conferences to keep communication open, and participated in several workshop meetings where partners met to discuss vegetation classification concepts, map classification and conventions, and analyses of AA data.

Final revisions to the vegetation classification and vegetation spatial databases (both WLNP and GNP) were developed and compiled in the suite of final products. Other spatial databases in the suite included locations of vegetation sampling plots, AA sites, aerial photo locations, and project boundary extent. All geospatial products are projected in Universal Transverse Mercator (UTM), Zone 12, using North American Datum of 1983 (NAD83).

Primary Partners and Responsibilities

The Waterton-Glacier IPP Vegetation Mapping Project was a cooperative effort among several agencies and organizations. The following lists the primary partners and their respective roles and responsibilities.

Center for Biological Informatics (USGS) and Biological Resource Management Division (NPS)

- Budgeting
- Project oversight and guidance

Waterton Lakes National Park (PC) and Glacier National Park (NPS)

- Advisory on the park's information and project support
- Host meetings, workshops, and training sessions
- GNP hiring of field crews for GNP effort; vegetation plot sampling, AA observation data, and database entry
- WLNP administration of contractors for WLNP effort; vegetation plot sampling, mapping, and AA field data

NatureServe and Montana Natural Heritage Program

- Project lead for vegetation classification
- Vegetation sampling design, vegetation plots training, and vegetation plot sampling
- Vegetation sampling analyses and derive vegetation classification, including keys and descriptions to plant communities of Waterton-Glacier IPP
- Advisory to map classification and mapping conventions
- Accuracy assessment field training and advisory in the analyses
- Overall management of PLOTS database, both vegetation plot sampling and AA data
- Provide documentation of methods and results regarding vegetation classification

Upper Midwest Environmental Sciences Center (USGS)

- Project lead for vegetation and land cover mapping of GNP
- Coordinate vegetation mapping efforts with WLNP
- Develop map classification and conventions for mapping Waterton-Glacier IPP
- Photointerpretation mapping and digital spatial data automation of GNP
- Accuracy assessment setup and data analyses for both WLNP and GNP
- Final spatial database development for both WLNP and GNP
- Develop spatial database products of vegetation sampling plot locations, AA site locations, vegetation map, and project boundary all supported with metadata documentation
- Provide documentation of methods and results regarding overall project, mapping, and AA
- Document FGDC-compliant metadata for all spatial data (with National Biological Information Infrastructure [NBII] compliant metadata for all vegetation spatial data)
- Compilation of final products and delivery to the USGS-NPS VMP, including reports, metadata, vegetation keys, classification lists, fieldwork data, spatial data, map composition, graphics, aerial photographs, and ground photos of vegetation work

Memorandum of Concurrence

A memorandum of concurrence conveying the partnership of WLNP and GNP in the Waterton-Glacier IPP Vegetation Mapping Project is provided in Appendix A: Waterton-Glacier IPP Memorandum of Concurrence.

Aerial Photography

Necessity of Aerial Photography

Essential for each VMP project is aerial photography. Aerial photographs provide the baseline imagery data for mapping plant communities and other landscapes. Vertical photographs (photographs taken with the aerial camera pointed straight down at the ground) collected with proper overlapping within each flight line permit an interpreter to study the photographs three-dimensionally with a stereoscope (Avery 1978). As ecological settings are taken into account in mapping plant communities, the ability to view aerial photographs in this way is fundamental.

A variety of film emulsions are available to choose from and Avery (1978) concludes no single film emulsion serves all purposes. For both WLNP and GNP, TC aerial photographs were collected August 1999 and were used as the primary imagery for photointerpretation mapping. Prior to obtaining the 1999 aerial photos, CIR aerial photographs were acquired in August 1997 of GNP, with intentions of having this set of photography be the primary photointerpretive base for mapping GNP. This CIR set, however, proved limiting for interpreting vegetation types of GNP, which led to the collection of the 1999 TC aerial photographs. In turn, the 1999 TC photographs posed its own set of unique limitations, giving credence to Avery's statement regarding lack of a single all-purpose film emulsion.

Thus, both CIR and TC emulsions provided strengths and limitations for photointerpretation. For GNP, the mapping was performed with the 1999 TC aerial photograph positive transparencies, particularly because it was of larger scale and the date was two years more current than the CIR. Still, the 1997 CIR aerial photographs were referred to heavily while mapping the 1999 TC photographs, applying the strengths provided from each photo set into the mapping. For WLNP, the mapping was performed over contact prints, which were produced from 1999 TC negative film. This presents a disadvantage for photointerpretation because the prints lack the sharp details that positive transparency film offers; many photo signatures on the prints lack distinctions that the film positives provide. The decision to purchase negative film rather than positive film for WLNP was for cost saving purposes.

Specifications of Aerial Photography

To assure stereo viewing and full aerial coverage, aerial photo missions were planned with a 60% forward-lap and 30% side-lap. Sets of 9 x 9-inch contact prints were produced for fieldwork use by mappers and vegetation crews.

The 1997 CIR aerial photographs were collected at 1:24,000-scale (Figure 14), with additional photos collected at 1:12,000-scale over selected areas of large lakes and large glaciers. The 1:24,000-scale photos were taken August 4–12, 1997, with the 1:12,000-scale photos within the same range of dates. A total of 1,320 photos were collected, 892 at 1:24,000-scale and another 418 at 1:12,000-scale.

Additional aerial photographs of same emulsion and scale—CIR, 1:24,000 and 1:12,000—were collected in August 1998 to fill holiday gaps from the 1997 photo mission and to retake selected frames that had either cloud cover or overexposure (due to large glacier fields). A total of 107 photos were collected, 87 at 1:24,000-scale and another 20 at 1:12,000-scale.

The 1999 TC aerial photographs were collected at 1:15,840-scale, although with two separate photo missions; one of WLNP (Figure 15) and the other of GNP (Figure 16). The WLNP photos were taken August 20, 1999, and the GNP photos were taken August 18–22, 1999. In all, 289 photos of WLNP and 1,618 photos of GNP were collected.

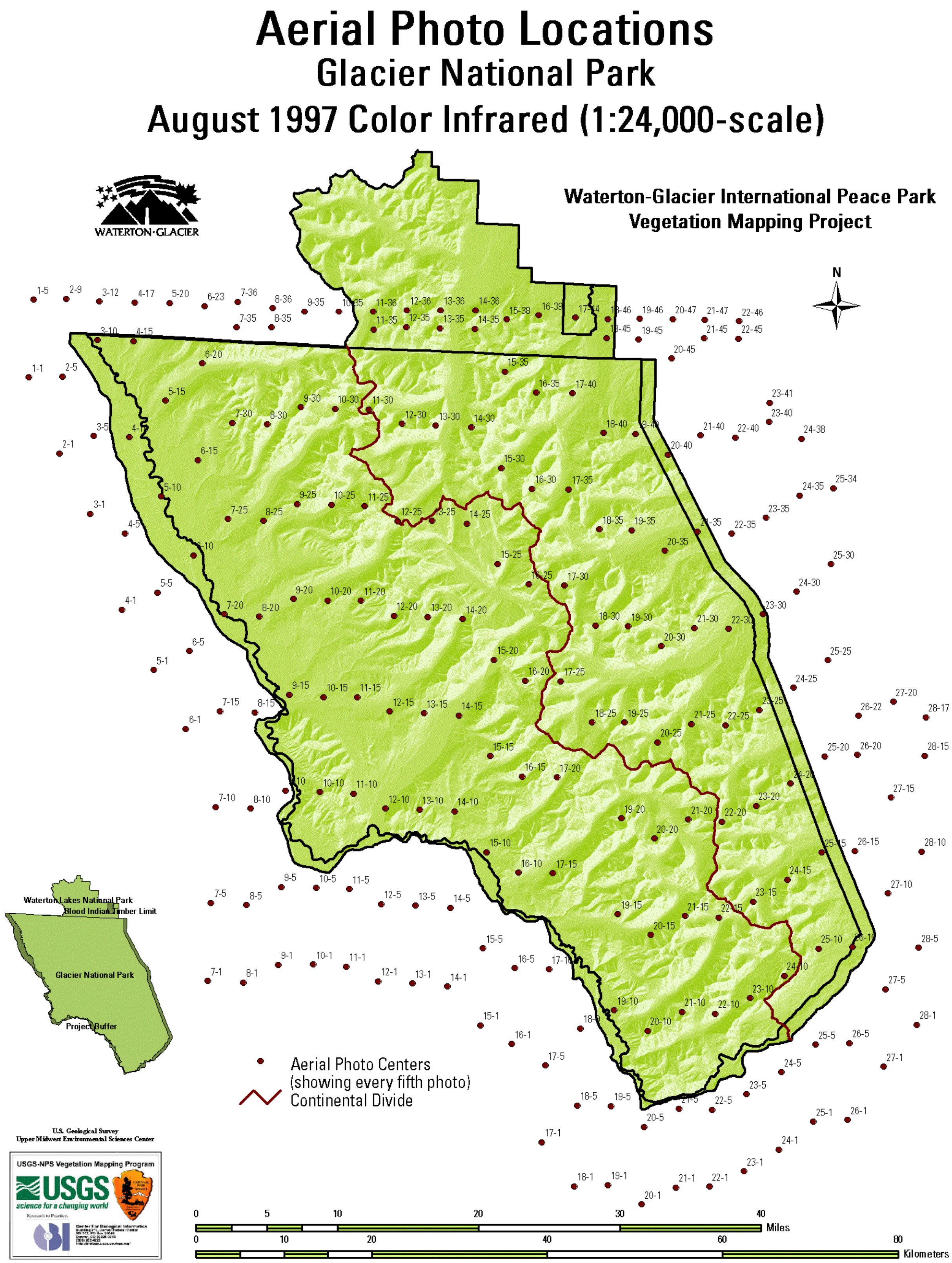

Figure 14. August 1997 color infrared aerial photographic coverage of Glacier National Park (every fifth photograph).

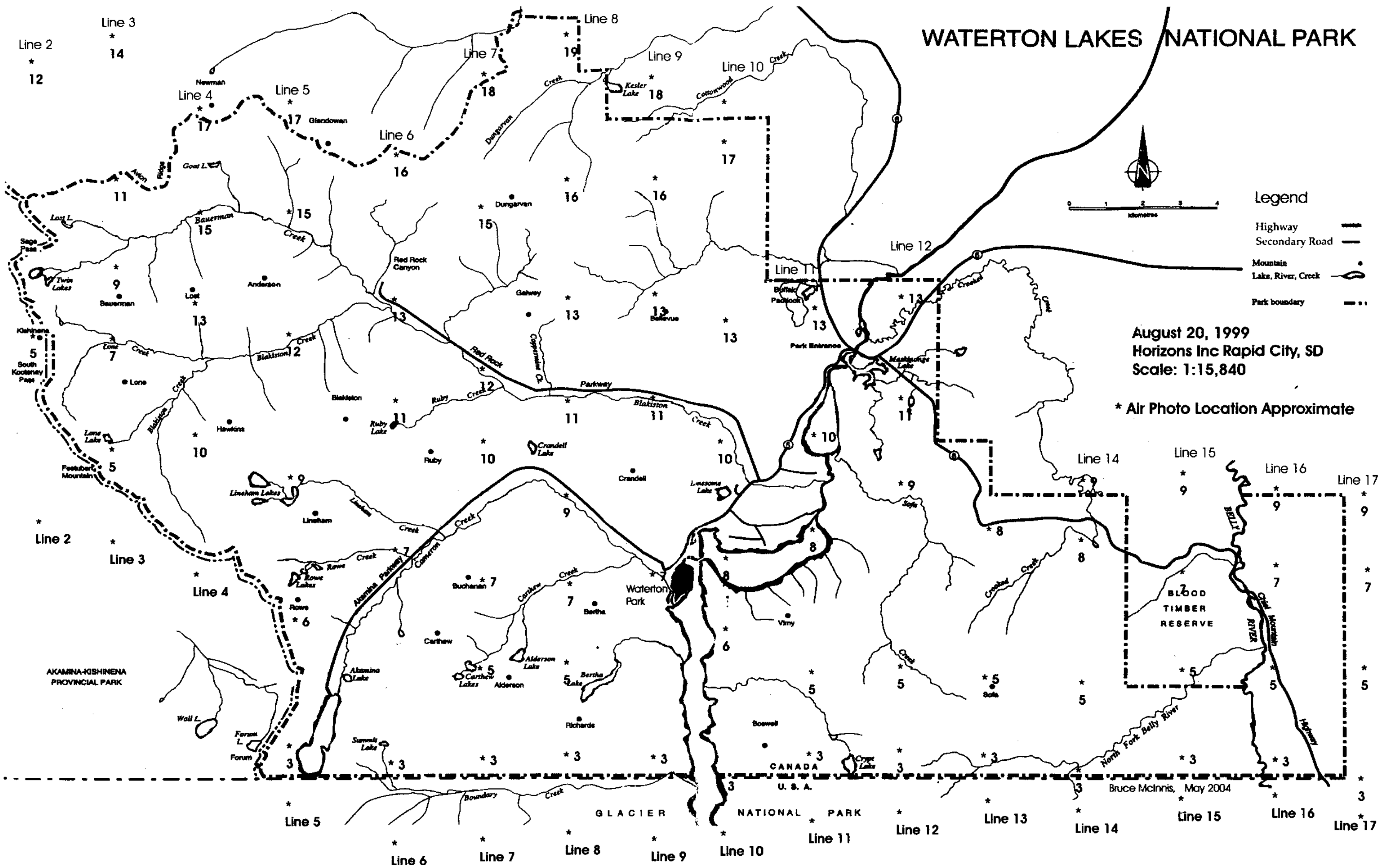

Figure 15. August 1999 true color aerial photographic coverage of Waterton Lakes National Park.

Aerial Photo Locations

Glacier National Park

August 1999 True Color (1:15,840-scale)

Figure 16. August 1999 true color aerial photographic coverage of Glacier National Park (every fifth photograph).

Although aerial photographs were collected at a specified scale, the resulting scale actually varies—even within a particular photo. Extreme elevation changes from high mountain ridges to valley bottoms resulted in a broad range of scales within an aerial photograph. For example, from a quick study of the 1999 TC aerial photograph covering the Swiftcurrent Campground/Many Glacier area, the scale at Grinnel Point is roughly 1:15,840, where the scale on the same photo at Swiftcurrent Campground just below Grinnel Point is around 1:24,000.

Table 3 gives details to the aerial photography acquired for the Waterton-Glacier IPP Vegetation Mapping Project.

Table 3. Aerial photography sets for the Waterton-Glacier International Peace Park Vegetation Mapping Project.

National Park	Photography Date	Film Type	Scale	Photos	Product	Company	Camera
Glacier	August 3–12, 1997	CIR Transparency (Positive)	1:24,000	892	Contact Prints	HJW & Associates	Zeiss RMK TOP 15
Glacier	August 3–10, 1997	CIR Transparency (Positive)	1:12,000	418	Contact Prints	HJW & Associates	Zeiss RMK TOP 15
Glacier	September 3, 1998	CIR Transparency (Positive)	1:24,000	87	Contact Prints	HJW & Associates	Zeiss RMK TOP 15
Glacier	September 3, 1998	CIR Transparency (Positive)	1:12,000	20	Contact Prints	HJW & Associates	Zeiss RMK TOP 15
Glacier	August 18-22, 1999	TC Transparency (Positive)	1:15,840	1,618	Contact Prints	Horizons, Inc. via DOI BOR	Zeiss RMK TOP 15
Waterton Lakes	August 20, 1999	TC Transparency (Negative)	1:15,840	289	Contact Prints*	Horizons, Inc. via DOI BOR	Zeiss RMK TOP 15

*Only frames covering the WLNP project area were printed, resulting in 181 contact prints.

We produced spatial database sets for use in GIS showing the locations of aerial photographs for the 1997 CIR (1:24,000-scale) and the 1999 TC aerial photo sets of GNP.

Strengths and Limitations of Aerial Photography

As mentioned above, each set of aerial photographs has its own strengths and limitations. Although photointerpretation mapping was performed over the 1999 TC aerial photos, the 1997 CIR aerial photos were used throughout the project to help distinguish ambiguous signatures on the TC photos. For instance, recognizing a stand of conifer-deciduous forest was much easier to discern on the CIR photos than on the TC photos, both in presence and in relative density, something critical for determining what map class to apply and where to draw polygon boundaries. This advantage, unfortunately, was not available to WLNP mapping. See Figures 17 and 18 for some comparison examples between the CIR and TC aerial photographs.

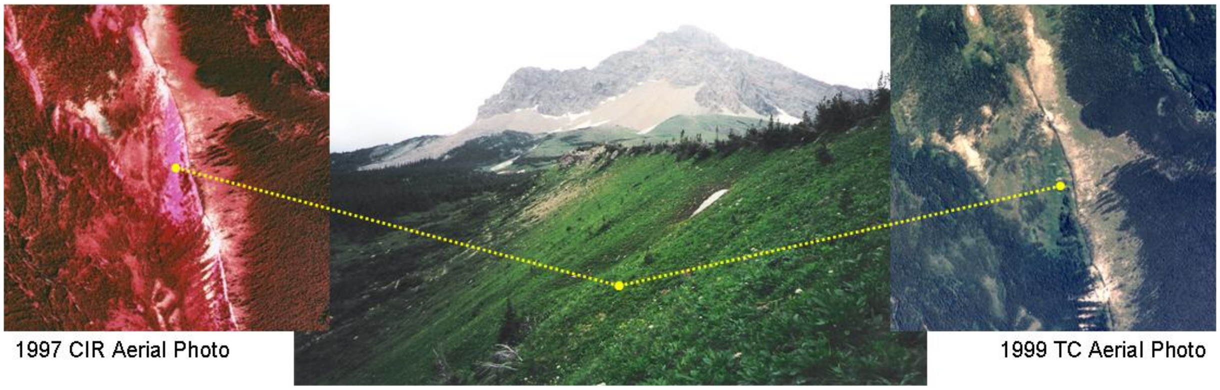

Figure 17. Comparison example between 1997 color infrared and 1999 true color aerial photographs. Center ground photo is of area designated on aerial photos; Lee Ridge area, Glacier National Park.

In this example, the color infrared photo provides a bright pink appearance of the east-face slope indicating to the photointerpreter this area is a wet-mesic slope from late snow melt. The same area on the true color photo, although appearing dark green, is somewhat less pronounced.

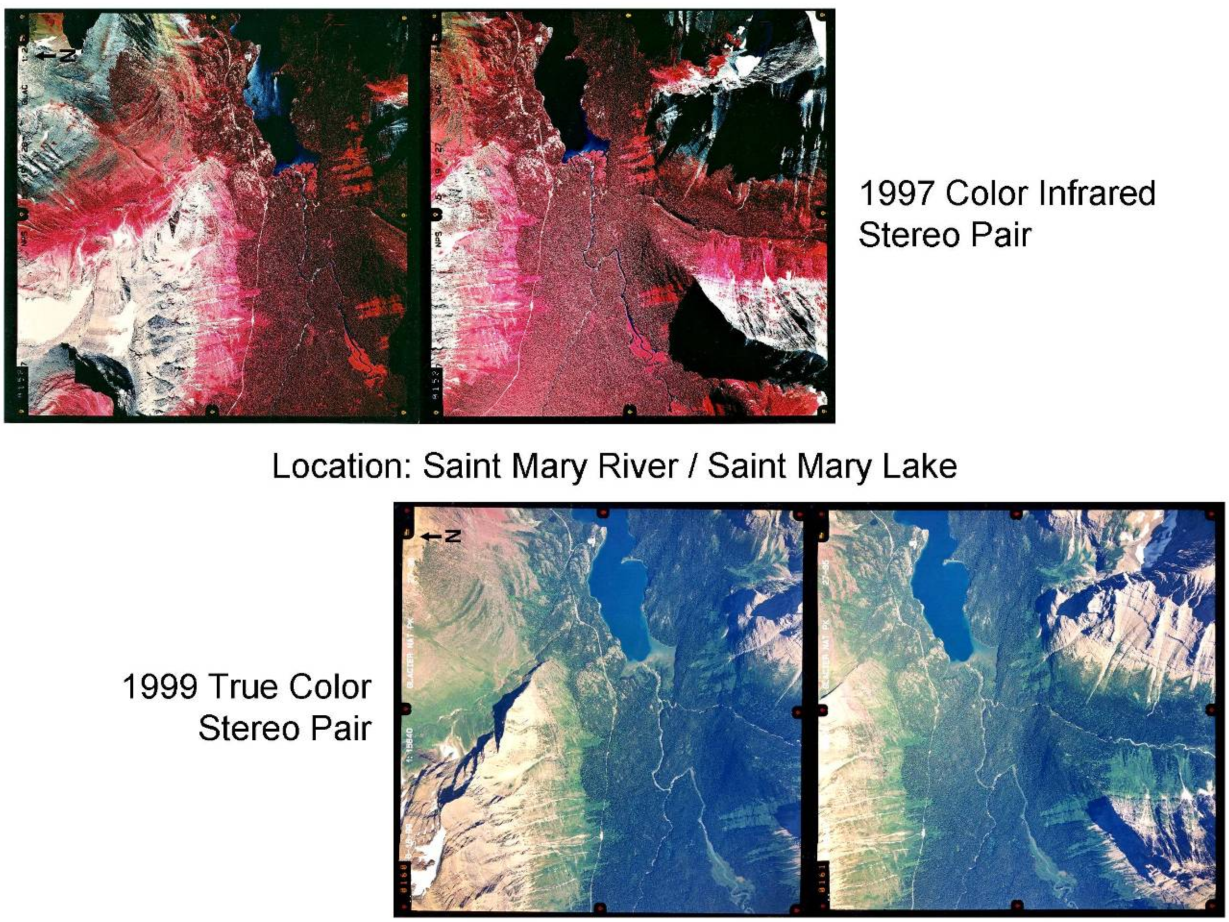

Figure 18. Comparison example between 1997 color infrared and 1999 true color stereo pairs; Saint Mary River / Saint Mary Lake.

Shadows on the color infrared photos are often too dark to see through, whereas on the true color photos, some underlying ground features can be seen.

Scoping Meeting

We officially launched the mapping project with a scoping meeting held at GNP headquarters June 9–11, 1998. Various cooperators joined together to discuss the project's objectives and methods, receive assignments, and view firsthand GNP's landscape. Individuals from GNP, WLNP, various USGS and NPS offices, Montana Natural Heritage Program (NHP), The Nature Conservancy (now NatureServe), and several other neighboring lands met to

- Inform WLNP and GNP staff and interested neighbors of the USGS-NPS VMP,
- Learn about WLNP and GNP management and science issues and concerns,
- Learn about existing data,
- Develop a preliminary schedule with assigned tasks,
- Get commitments from WLNP and GNP,
- Begin a process to define possible cooperation with neighbors and partners, and
- Define the project boundary.

From the scoping meeting, we identified the following management challenges to where vegetation mapping information could be applied:

- Effects of trampling of alpine vegetation,
- Wildlife habitat monitoring and management, including wolves, grizzly and black bears, lynx, bald eagle, and many other species,
- Habitat mapping for wildlife species,
- Locations of wet alpine meadows,
- Successional patterns of avalanche chute vegetation,
- Effects of fire exclusion,
- Rare plant monitoring,
- Exotic weed invasions, e.g., leafy spurge invasion in prairies west of the CD, brome and timothy on prairies east of the CD, knapweed along roads,
- Small prescribed burn program, possible encroachment on neighbors along GNP's eastern boundary,
- Condition and distribution of aspen clones,
- Development of park flora,
- Cattle trespassing from neighbors along GNP's eastern boundary,
- Lodgepole pine mortality from beetles,
- Snag density,
- Fuel loads,
- Conifer encroachment (ponderosa pine, lodgepole pine, Douglas fir) onto prairies west of the CD (wolf den implications),
- Whitebark pine and limber pine mortality,
- Relationship between ponderosa pine and fire, and
- Restoration planning.

Interim Meetings

A subsequent meeting was held at the USGS UMESC in December 1998 to further discuss classification and mapping and to plan next steps, particularly with the vegetation plot sampling effort (Figure 19). A status of the gradsect (gradient-oriented transect) sampling analysis and biophysical units was provided for review and comment. The project boundary was also determined, and a schedule for the following field seasons was established.

Figure 19. December 1998 interim meeting at the Upper Midwest Environmental Sciences Center to discuss the classification and plan the vegetation plot sampling scheme.

In June 1999, ecology and mapping teams convened at GNP headquarters to review field project goals, partners, and proposed products. Use of the environmental stratification map was explained, and training in sampling vegetation was provided, including infield training plots.

In July 2001, a vegetation classification workshop was held at GNP amongst classifiers. At the vegetation classification workshop, the status of the vegetation classification was reported and current classification challenges along with resolutions were discussed. One month later, a vegetation map classification workshop was held at GNP amongst both classifiers and mappers. At the map classification workshop, map issues related to the classification challenges from the vegetation classification workshop were discussed with potential resolutions. Numerous map class concepts were addressed at this meeting and subsequently field tested.

In March 2002, another vegetation classification workshop was held in Calgary, Alberta, Canada. Here, the classifiers reviewed major concepts within the vegetation classification, and clarified several "rules" in identifying associations. The results were shared with mappers during a hands-on workshop held at the UMESC in April 2002, where mappers from both WLNP and GNP met to discuss and resolve numerous mapping issues.

In addition to these more formal-like meetings, several other smaller, informal meetings and conference calls transpired throughout the entire classification and mapping effort, providing invaluable collaboration amongst partners for identifying next steps and discussing classification and map issues.

Interim Report

An interim report was submitted to the USGS-NPS VMP, GNP, and WLNP staff in December 2002 (Bradley et al. 2002) discussing methods and results of the Waterton-Glacier IPP classification and mapping effort from its inception through 2002. The purpose of this report was to provide VMP and park staff the status of the classification and mapping efforts, along with preliminary results from the vegetation plot sampling data.

Vegetation Classification Report

In April 2004, NatureServe published a vegetation classification report for Waterton-Glacier IPP (Reid et al. 2004), complete with methodology and results, including vegetation classification descriptions and keys. Although subsequent edits to this vegetation classification report have transpired since its release in 2004 (due to further field information attained from mapping efforts and AA observation plots), it provided a firm footing of the vegetation classification for the entire Waterton-Glacier IPP.

Project Boundary and Map Extent

The project boundary and map extent includes all lands within the Waterton-Glacier IPP along with additional lands or environs immediately surrounding the park (Figure 20). For the WLNP mapping effort, park lands cover approximately 49,942 ha (123,408 acres) in area—although WLNP commonly reports 50,500 ha (124,788 acres)—with additional lands of the Blood Indian Timber Limit adding another 1,931 ha (4,771 acres). For the GNP mapping effort, the park lands cover 408,056 ha (1,008,328 acres) in area, with environs including an approximate 1.6 km (1.0 mile) buffer around the entire park, less the northern park boundary bordering Canada. East of the CD, the extended lands are a consistent 1.6 km (1.0 mile) buffer, and include lands of the Blackfeet Indian Reservation (from the Canada-United States International Border to just south of East Glacier) and the Lewis and Clark National Forest with some private ownership (from just south of East Glacier to the Continental Divide at Marias Pass). West of the CD, the environs are of variable size (as derived by GNP staff), becoming as narrow as nearly 60 m (197 ft) from the park boundary to as broad as nearly 4.0 km (2.5 miles). Lands west of the CD include the Flathead National Forest, private ownership, and British Columbia, Canada; a 100 m (328 ft) buffer extends into British Columbia, Canada north of GNP. The environs to GNP add 34,916 ha (86,278 acres) to the GNP mapping effort. All environs add 36,847 ha (91,049 acres) to the entire Waterton-Glacier IPP mapping effort. Thus, the full map extent area (combined Waterton-Glacier IPP and respective environs) is 494,845 ha (1,222,789 acres). Table 4 provides a summary report on map extents for each individual park, as well as the entire Waterton-Glacier IPP. The chart in Figure 21 shows the map extent areas from a graphical perspective.

Table 4. Summary report of project extents for the Waterton-Glacier International Peace Park Vegetation Mapping Project.

Area (ha)	Park	Environs	Park/Environs	% of Map
WLNP Effort	49,942	1,931	51,873	10%
GNP Effort	408,056	34,916	442,972	90%
Combined Effort (WLNP and GNP)	457,998	36,847	494,845	100%

Figure 20. Project boundary extent of the Waterton-Glacier International Peace Park Vegetation Mapping Project.

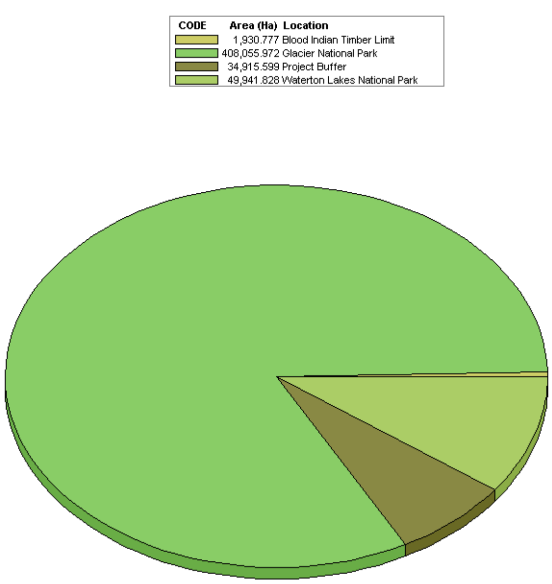

Figure 21. Area (ha) comparison of locations within the Waterton-Glacier International Peace Park Vegetation Mapping Project.

Two spatial database sets for use in GIS were created for the Waterton-Glacier IPP Project; one for the WLNP mapping effort and the other for the GNP mapping effort. These two spatial databases match each other with exactitude (seamless in polygon and attribute) at the Canada-United States International Border. The two spatial databases were kept separate from each other since they were produced by independent mapping groups employing base data of differing qualities and using somewhat different map processes.

Minimum Mapping Units

We applied the USGS-NPS VMP's standard minimum mapping unit (MMU) of 0.5 ha (1.2 acres) for mapping vegetation types and general land cover of Waterton-Glacier IPP and environs. We applied a secondary MMU of 2.0 ha (4.9 acres) for physiognomic changes in the vegetation within a particular map class. We used MMU templates to help determine minimum polygon size on the photographs during our mapping. Because angle distortions are inherent to nonrectified aerial photos, and extreme scale changes occurred from high ridges to valley bottoms (e.g., roughly 1:15,840-scale at Grinnel Point and 1:24,000-scale at Swiftcurrent Campground below Grinnel Point, as previously discussed), the MMU was applied liberally to reduce mapping omissions. Thus, polygons smaller than the MMU are inherent to the vegetation spatial databases. For further details regarding the MMU, see Results in the Vegetation Mapping section.

Vegetation and Map Classification Organization

Because vegetation associations of Waterton-Glacier IPP are rooted in the NVC, it is most convenient to structure and organize the associations according to the NVC hierarchical structure. The dilemma we found ourselves in, however, is that the NVC is presently going through revision, including major adjustments to the classification hierarchical structure. The revised NVC version will soon replace the original NVC version, which was initially adopted by the FGDC in 1997. So, at the conclusion of this project, we find ourselves at a turning point with the 1997 version of the NVC becoming historical and a second version of the NVC in its late gestation period.

Throughout the duration of this project, we have organized the vegetation classification within the context of the 1997 version of the NVC physiognomic hierarchy. Throughout this report—appendixes included—where we list plant associations and alliances, we also organize the vegetation types according to the 1997 version of the NVC. This is for two reasons. The practical reason is that all the association-level information resides in NatureServe's databases, which is organized according to the 1997 NVC hierarchy. The other reason is that the revised NVC hierarchy is still in draft form, and individual associations and alliances have not yet been reviewed systematically to determine how they should be organized in the proposed new hierarchy, particularly in the finer levels (Level 5 Macrogroup and Level 6 Group). We did not want to organize and present association and alliance types of the Waterton-Glacier IPP vegetation classification into a draft hierarchy when changes would probably occur over the next year.

However, for purposes of organizing the map classification and spatial databases, we derived an estimation of what the hierarchy structure within the revised NVC version might look like. We based this on a proposed hierarchical structure that is being tested for Levels 1 and 2, with Levels 3, 5, and 6 in the proposal stage having little or no validation. For non-vegetated map classes, we derived adhoc hierarchical level names merely to provide a legend output when constructing map layouts from the spatial databases. From here on out, we refer to our elucidation of the up-and-coming revised version of the NVC as "NVCvr2x."

Below in Table 5 we present NVCvr2x, which we will use throughout the report for organizing the map classification used in the Waterton-Glacier IPP vegetation mapping project. In the NVCvr2x version, there are six hierarchy levels above alliances and associations. To simplify our presentation, however, we do not show all six levels in our table. (For simplicity, we do not show Level 4, Division). This draft hierarchy will undergo testing in a number of pilot projects around the country over the next six to nine months. It is quite probable the six levels within the NVCvr2x will be revised in name or concept during this time. Nevertheless, we think the NVCvr2x version is a useful, ecologically meaningful way to organize the map classification for the Waterton-Glacier IPP vegetation mapping project.

Table 5. Organization for presenting map classification, using proposed levels of National Vegetation Classification Version 2 - Working Draft.

NVCvr2x Level	NVCvr2x Level Name
L1	Forest and Woodland Class
L2	Temperate Forest and Woodland Subclass
L3	Cool Temperate Forest and Woodland Formation
L5	Rocky Mountain Subalpine and High Montane Forest and Woodland MacroGroup
L6	Rocky Mountain Subalpine Mesic Conifer Forest and Woodland Group
L6	Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland Group
L6	Rocky Mountain Subboreal and Montane Conifer Forest Group
L6	Rocky Mountain Subalpine (Cool) Deciduous Broadleaf and Mixed Forest Group
L5	Rocky Mountain Lower Montane Forest and Woodland MacroGroup
L6	Rocky Mountain Montane Limber Pine - Juniper Woodland Group
L6	Rocky Mountain Mesic Montane Conifer Forest Group
L6	Northern Rocky Mountain Ponderosa Pine Woodland Group
L6	Rocky Mountain Cedar - Hemlock Rainforest Group
L3	Temperate Wetland Forest and Woodland Formation
L5	Rocky Mountain and Great Basin Wet Forest MacroGroup
L6	Northern Rocky Mountain Conifer Swamp and Riparian Forest Group
L6	Rocky Mountain Conifer Swamp and Riparian Forest Group
L6	Northern Rocky Mountain Montane Riparian Forest Group
L1	Shrubland and Grassland Class
L2	Temperate and Boreal Grassland, Meadow, and Shrubland Subclass
L3	Temperate Grassland, Forb Meadow, and Shrubland Formation
L5	Northern (Cool) Rocky Mountain - Vancouverian Montane Shrubland and Grassland MacroGroup
L6	Northern Rocky Mountain Avalanche Chute Shrubland Group
L6	Northern Rocky Mountain Lower Montane Deciduous Shrubland Group
L6	Rocky Mountain Montane Grassland Group
L5	Rocky Mountain Successional Vegetation MacroGroup
L6	Rocky Mountain Early Successional Forest, Shrubland, and Forb Meadow Group
L3	Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation
L5	Western North America Freshwater Shrub, Marsh, and Wet Meadow MacroGroup
L6	Rocky Mountain Subalpine and Montane Riparian Shrubland Group
L6	Rocky Mountain Wet Meadow and Snowbed Group
L6	Western North America Emergent Marsh Group

NVCvr2x Level	NVCvr2x Level Name
L6	Rocky Mountain Shoreline Vegetation Group
L1	Semi-Desert Scrub and Grassland Class
L2	Cool Semi-Desert Scrub and Grassland Subclass
L3	Cool Semi-Desert Scrub and Grassland Formation
L5	Northern Great Basin Shrub Steppe and Grassland MacroGroup
L6	Inter-Mountain Basin Montane Sagebrush Steppe Group
L1	Polar and High Montane Vegetation Class
L2	Temperate and Boreal Alpine Vegetation Subclass
L3	Alpine Scrub, Forb Meadow, and Grassland Formation
L5	Rocky Mountain Alpine Scrub, Forb Meadow, and Grassland MacroGroup
L6	Rocky Mountain Alpine Dry Scrub and Fell-field Group
L6	Rocky Mountain Alpine Meadow Group
L1	Nonvascular and Sparse Vascular Vegetation Class
L2	Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vascular Vegetation Subclass
L3	Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation
L5	Rocky Mountain Cliff, Scree, Talus, and Other Rock Vegetation MacroGroup
L6	Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation Group
L1	Agricultural Vegetation Class
L2	Herbaceous Agricultural Vegetation Subclass
L3	Cultivated Crop Formation
L5	Temperate and Tropical Row Crop/Close Grown Crop MacroGroup
L6	Temperate Row Crop/Close Grown Crop Group
L1	Non-vegetated Land (non-NVC Class)
L2	Terrestrial Natural Non-vegetated Land (non-NVC Subclass)
L3	Glacier, Ice, and Snowfield (non-NVC Formation)
L5	Perennial Glacier and Snowfield (non-NVC MacroGroup)
L6	Mountain Perennial Glacier and Snowfield (non-NVC Group)
L2	Terrestrial Cultural Non-vegetated Land (non-NVC Subclass)
L3	Water-body (non-NVC Formation)
L5	Open Water-body (non-NVC MacroGroup)
L6	Open Water Stream/River and Lake/Pond (non-NVC Group)
L3	Developed Land (non-NVC Formation)
L5	Developed and Other Cultural Area (non-NVC MacroGroup)
L6	Developed Area (non-NVC Group)
L6	Other Cultural Area (non-NVC Group)

Vegetation Classification

Methods

Pre-field Methods

Preliminary Classification List

Developing a preliminary list of vegetation types—plant associations or comparable units—potentially occurring at Waterton-Glacier International Peace Park (IPP) was necessary to provide us with an estimate of plant associations, which, in turn, allowed us to estimate how many quantitative plots we would need to adequately sample the vegetation of Waterton-Glacier IPP. There were substantial plot data already available from previous projects, which we were able to integrate. Subtracting the existing data from our sampling goal, we then could estimate the number of plots remaining for collection. Overall, the preliminary classification provided both classifiers and mappers guidance to possible vegetation types at Waterton-Glacier IPP, which could be used as a tool for planning and as an approach for classifying and mapping plant communities.

We began generating the preliminary classification by accessing NatureServe's central ecology databases and exporting 350 associations from those databases for western and central Montana. We tabularized the list for review and had each association rated based on the following criteria of occurrence at Waterton-Glacier IPP:

- Definitely would occur,
- Probably would occur, and
- Definitely would not occur.

We eliminated those associations determined as "definitely would not occur" and then, upon additional review, added several other potentially occurring vegetation types. All types were coded with "GNP" followed by a sequential number (e.g., GNP001, GNP002). We reviewed other sources, finding additional vegetation types within data from Achuff et al. (2002a) and Damm (Christian Damm, unpublished data, 1999), and added them to the preliminary list, sequentially coding those with "WLNP" and "CDamm," respectively.

Damm's data for his dissertation (Damm 2001) became available to us in mid-2001 in spreadsheet format providing us locational data and Damm's assigned community type name. We reviewed 630 plots and made an attempt to assign each to an existing National Vegetation Classification (NVC) type. We adopted into our preliminary classification matrix any potentially new types from our NVC assignment of Damm's community types.

We then organized this list of associations by life zones—alpine, subalpine, montane, and foothills—as a surrogate to stratify types by elevation. We included frequency of existing plots for each association listed. We also noted types occurring only east or only west of the Continental Divide (CD) and listed additional information from plots relating to environmental variables, which we would use later to complete a gradsect (gradient-oriented transect) sampling analysis (as described in Field Sampling section below).

The resulting preliminary classification matrix listed 215 plant associations for the Waterton-Glacier IPP area, along with an estimated number of sampling plots still needed per vegetation type. This preliminary classification matrix is listed in Appendix B: Preliminary Vegetation Classification of Waterton-Glacier IPP.

Field Methods

Our primary purpose in collecting plot data for classifying vegetation was to obtain quantitative data describing composition and structure of vegetation and associated environmental conditions. These data became the basis for classifying and describing the vegetation of Waterton-Glacier IPP. The field methods we used for conducting vegetation sample plots followed Vegetation Mapping Program (VMP) standards (The Nature Conservancy and Environmental Systems Research Institute 1994b) and are widely used by ecologists. The sampling data acquired during this project also contributed to the understanding of vegetation relationships across broader landscapes beyond Waterton-Glacier IPP's boundaries.

Staff from Glacier National Park (GNP) and Waterton Lakes National Park (WLNP) defined additional data fields on the plot sampling form to meet park and fire management needs. To view a plot sampling form with the individual data field descriptions, see Appendix C: Plot Sampling Form and Field Manual. Fuels data were collected following methodology of Brown (1974) and Burgan and Rothermel (1984) with some modifications.

Field Sampling Approach

The sampling area included all of GNP and WLNP plus 1.6 km immediately beyond GNP's eastern boundary into the Blackfeet Indian Reservation. Damm's alpine data of GNP (Damm 2001) was sufficient for our vegetation analyses, so no additional alpine plots were needed for the entire Waterton-Glacier IPP area. For the remaining life zones (subalpine, montane, and foothills) of GNP, in order to cost-effectively capture the full spectrum of vegetation types, we needed to optimally locate our vegetation sampling plots.

One method that could assist us in identifying optimal areas for vegetation sampling plots is the gradsect (gradient-oriented transect) sampling approach (Austin and Heyligers 1991; Gillison and Brewer 1985). This approach identifies transects having the highest environmental gradients within a defined area, with an objective of capturing maximum range of vegetation variation, resulting in increased efficiency when sampling a large environmentally and vegetatively diverse area. We adopted this approach and used a modified gradsect technique to determine sampling locations, consisting of a geographic information system (GIS) assisted analysis of biophysical data layers combined with professional judgment. This technique divided the landscape into biophysical classes based on factors thought to have the greatest influence on vegetation distribution. In our analysis for GNP, spatial data from several environmental variables were coupled with a digital elevation model (DEM, resolution of 30 m), with the assumption this would predict vegetative diversity. A working group of ecologists familiar with the Northern Rocky Mountains selected the GIS driving variables. These variables consisted of:

- Elevation,
- Aspect,
- Soils, and
- Disturbance (as captured in fire history).

We also recognized the CD as a convenient and ecologically significant demarcation among large-scale biophysical phenomena occurring predominantly either east or west of the CD. For example, areas east of the CD have a much greater frequency and strength of downslope, drying (Chinook) winds. Thus, we developed two separate environmental stratifications for analysis, one east of the CD, and the other west of the CD.

See Appendix D: Gradsect Sampling Design Methodology for classes delineated for each variable and the complete methodology. Using GIS, we tallied environmental stratification units representing unique spatial combinations of driving variables, thus deriving polygons with these environmental stratification codes; these are termed biophysical units (BPUs). An example of a BPU is one having "Deep soils of argillite or quartzite, 1351–1700 m in elevation, with pre-1840 fire, on north aspects."

If possible, we selected at least three polygons per BPU for sampling and distributed them throughout the range of the BPU. We masked polygons of hazardous areas from the site selection; e.g., polygons where the average slope was >50 degrees. The average polygon size was 7.45 ha, and required on average approximately 800 m of hiking on moderate terrain to access.

At GNP, the vegetation plot sampling crews were led by investigators with experience in sampling plant communities of national parks and similar lands. The preliminary classification list of 215 plant associations provided a starting point for naming communities sampled in the field. The sampling strategy was to collect between three and five plots for every association within the GNP project area. However, some common associations were sampled more often, whereas some rare types were sampled less.

Because WLNP had been previously sampled (Achuff et al. 2002a) in 1994–95, plot data were available and sufficient for classifying vegetation. Thus, a sampling design as prepared for GNP was not necessary for WLNP. Several major vegetation types known to occur in WLNP, however, were not sampled by the previous investigators. Therefore, those types were specifically targeted for vegetation sampling plots in 1999 based on known locations of these types.

Vegetation sampling plots in both GNP and WLNP were sampled between June and September for each field season, permitting progressive sampling from the lowest to the highest elevations, and the identification of early- and late-flowering plant species. Field data were collected in approximately eight-day duration trips by one to two teams consisting of two or three researchers each.

Vegetation Plot Data Collection

Glacier National Park

In many instances, BPUs helped locate vegetation plots for sampling. These were sampled in a logistically feasible manner, meaning areas were targeted on a drainage-by-drainage basis with community phenology being a constraining factor. Polygons of BPU in more remote, and usually of higher elevation, were sampled later in the season via backpacking expeditions.

The GIS support team at GNP provided conveniently sized, topographic base maps at a scale corresponding to the aerial photographs, with BPUs superimposed. The aerial photographs were also valuable in navigating to BPU polygons and were useful in portraying vegetation diversity when obscured at ground-level. This approach facilitated the efficient sampling of numerous BPU polygons having multiple vegetation types present. Sampling also occurred outside of BPU polygons, in communities identified as “previously unsampled or unique” by the field crew lead.

Sampling west of the CD in 2001 was less constrained by adherence to BPUs. Examination of aerial photographs revealed numerous spectral signatures were not being sampled when a single BPU was chosen to represent a unique combination of variables. Thus, representative and repeatable photo signatures were targeted for sampling with plots, particularly when they were in the proximity of, or along the trail to, a targeted BPU. Sampling plots (Figure 22) were placed “without preconceived bias” in vegetation representative of the whole polygon, and as homogeneous as possible in structure, composition, and abiotic variables. Multiple plots per BPU polygon were collected when aerial photographs or field reconnaissance revealed multiple vegetation types. Spatial coordinates (X-Y) were collected for the vegetation sampling plot using a Rockwell Precision Lightweight GPS Receiver (PLGR) and were permanently marked at the plot’s center by an eight-penny nail and engraved tag.

Figure 22. Example of a vegetation sampling plot.

The vegetation sampling plot shape was generally circular with the size dependent on the dominant life form present (Table 6). Under exceptional circumstances, plot shape deviated from circular to capture quantitative information from linear vegetation types (e.g., riparian stringers); the total plot area remained consistent to the dominant life form criteria.

Table 6. Plot sizes used for sampling vegetation.

Vegetation Class	Standard Plot Dimensions	PLOT AREA
Forest	11.35 m radius or 20 m x 20 m	404 m^2 or 400 m^2
Woodland	11.35 m radius or 20 m x 20 m	404 m^2 or 400 m^2
Shrubland	11.35 m radius or 20 m x 20 m	404 m^2 or 400 m^2
Dwarf-shrubland (heath)	5.65 m radius or 10 m x 10 m	100 m^2
Herbaceous	5.65 m radius or 10 m x 10 m	100 m^2
Nonvascular	2.82 m radius or 5 m x 5 m	25 m^2

Again, see Appendix C for both the plot survey form and the field manual for sampling vegetation. Within each plot, researchers estimated and recorded an array of vegetation and environmental data using the field forms and data definitions as described in Appendix C. Four general categories of data were collected for each vegetation sampling plot:

- Location and plot identifiers,
- Environmental descriptors,
- Vegetation descriptors, and
- Fuels model factors.

The specific data components collected for each of these four categories are listed in Table 7.

Table 7. General plot data categories and specific data components collected at each vegetation plot.

Plot Data Category	Data Components
Location and Plot Identifiers	Plot code, park name, site name, state, county, quad name, quad code, GPS unit, GPS file ID, UTM coordinates, UTM zone, GPS error, 3D differential, survey date, surveyor names, directions to plot, plot dimensions, photograph documentation
Environmental Description	Elevation, slope, aspect, topographic position, landform, geology, Cowardin wetland type, hydrologic regime, floodplain width and gradient, distance to water, standing water depth, ground cover, soil texture, soil drainage, evidence of disturbance and animal use
Vegetation Description	Height and cover of all strata, cover by species, physiognomic type, provisional association name, plot representativeness
Fuels Model Factors	Downed wood tally, litter and duff depth, dead fuel depth, sound and rotten wood, herbaceous fuel type, herbaceous fuel height, percent live herbaceous fuel, shrub fuel type, shrub waxiness, litter and woody fuel source and cover

Further explanations of these four categories follow.

Location and Plot Identifiers

The bounds or radii of each vegetation sampling plot were marked using measuring tapes. At the center of each plot, the X-Y coordinates were measured with hand-held GPS receivers—projected in Universal Transverse Mercator, Zone 12, using datum of North American Datum of 1983. Other data fields documenting unique plot identifiers and describing the general location of each plot, as listed in Table 7, were also recorded and are described in detail in Appendix C.

Environmental Description

The physical characteristics of each vegetation sampling plot were documented by a combination of categorical and narrative fields, as listed in Table 7. These included categorization of physical site features (e.g., elevation, slope, aspect, topography), hydrology, geology, and soils. Characterization of the ground surface was made by estimating the cover of rocks, sand, litter, bare soil, moss, and lichen. Animal use evidence and various pathogen or human disturbances were also recorded. A narrative field was provided for describing the plot setting and any physical factors influencing the vegetation. Again, see Appendix C for further details.

Vegetation Description

To characterize species composition and abundance, all vascular plant species within each vegetation sampling plot were identified by scientific name, and the canopy cover by strata was estimated to the nearest cover class (Table 8). Consistent and repeatable cover estimates were obtained by relating the area occupied by an individual species to the area of the entire vegetation sampling plot. Species were recorded by scientific name familiar to researchers and subsequently synonymized with the nomenclature of Kartesz (1999). To characterize the vertical structure of the stand, vascular vegetation in each vegetation sampling plot was assigned to one of 10 physiognomic strata (listed in Appendix C). For each stratum, the dominant plant species, average height and canopy cover class (Table 8) were recorded. Voucher specimens were collected for all unknown taxa for subsequent identification by project personnel or taxonomic authorities. Provisional plant association names were assigned to each vegetation sampling plot using the preliminary association list and professional judgment. The list of provisional plant association names and number of vegetation plots sampled within each was updated throughout the field seasons.

Table 8. Vegetation cover and height classes used for vegetation plot sampling.

Species Canopy Cover Classes		Height Classes	
Code	Range (%)	Code	Range (m)
T	0-1	1	<0.5
P	>1-5	2	0.5-1
1	>5-15	3	1-2
2	>15-25	4	2-5
3	>25-35	5	5-10
4	>35-45	6	10-15
5	> 45-55	7	15-20
6	>55-65	8	20-35
7	>65-75	9	35 - 50
8	>75-85	10	>50
9	>85-95		
10	>95		

An initial attempt to describe tree population structure by narrow diameter classes was abandoned; it was too time consuming and partly redundant with recording tree canopy cover by size classes (e.g., seedling and saplings; pole sized; larger than pole-sized). For woodlands and forests, stand age, or the time of the last stand-replacing fire, was approximated by coring and counting annual rings (as well as determining height and diameter breast height [dbh]) of a healthy tree representative within the largest diameter class.

Ecological (e.g., tree pathogens present) and abiotic (e.g., elevation, aspect, slope) variables collected in the field are listed in Appendix C.

Fuels Model Factors

In addition to vegetation and ecological data, a fuel inventory protocol was undertaken in GNP at nearly every sampling point during the 1999 and 2000 field seasons (Brown 1974; Burgan and Rothermel 1984). Fire fuels data are considered an essential value-added aspect of field data collection and are used in developing FARSITE (Fire Area Simulator) models. The data were provided to the park's fire ecologist for use in developing a park-wide fuels layer for the GNP. The fuels layer was used to model fires during the 2001 fire season and also used in conjunction with burn severity data to update the fuels layer to reflect recent fires (Caroline Noble, written commun., August 2007). In the future, the fuels data may be used to investigate developing custom fuels models for GNP that would be more reflective of diverse post-beetle and varied successional landscapes than a traditional fuels model can provide.

General Information

Other characteristics of the vegetation sampling plot and of the larger stand were also recorded, such as general observations on the relationship of site conditions and vegetative patterns, site disturbance history, and how well the vegetation sampling plot represented the stand at large. The overall character of vegetation and features of each vegetation sampling plot were captured with one or two 35 mm color slides (subsequently scanned to digital) or digital photographs.

The 1999 field season was devoted exclusively to sampling vegetation plots east of the CD. In the 2000 season, the vegetation plot sampling was distributed about two thirds east of the CD and one third west of the CD. The focus of vegetation sampling plots in the 2001 and 2002 field seasons were primarily west of the CD. One or two fuel inventory personnel would join and assist the vegetation crew if their fuel inventory sampling concluded prior to the vegetation plot sampling.

Glacier NP Grasslands East of the Continental Divide

Grasslands of GNP were sampled in a study led by botany staff at GNP. While the methods were not exactly the same as those we used for GNP, the data were comparable and useful in classifying grassland vegetation of Waterton-Glacier IPP. A total of 155 samples were collected from grassland areas at GNP east of the CD in summers of 1999–2001. These samples included complete species lists and cover estimates for all species, and strata and ground cover estimates. For complete methodology of this study, refer to Shea et al. (unpublished data, 2004).

Waterton Lakes National Park

Much of the WLNP vegetation data was acquired prior to the inception of this joint project. An additional 54 vegetation plots were sampled in 1999 to address gaps identified in the preliminary vegetation classification for Waterton-Glacier IPP (Appendix B). The vegetation plot sampling methods for WLNP were closely comparable to GNP, including the plot size employed based on the physiognomic class criteria, and field data collection and forms. One significant site variable uniquely collected by WLNP was "moisture regime" rated on a seven-class ordinal scale. However, the GNP "soil drainage" variable (collected only in GNP and not in WLNP), with its six-class scale, captures some of the information implicit in the "moisture regime."

Vegetation Plot Data Management

All together, we compiled 1,113 vegetation sample plots of the Waterton-Glacier IPP project area into one database. These vegetation sample plots included plots collected specifically for this project plus existing plots from other studies that we found functional for the classification analyses (Table 9; Figure 23). The vegetation sample plot data were entered into the PLOTS Database System, which was developed expressly for the NPS Inventory and Monitoring Program (I&M), where the database fields mirrored those of the field form we used for this project. Quality control of data entry and species nomenclature was performed by natural resource staff at GNP, Montana Natural Heritage Program ecologists, and regional NatureServe staff. Discrepancies among the data sets (e.g., taxonomy differences, assignment of woody taxa to strata, coding of environmental factors) were addressed as needed during the data entry.

Table 9. Number of quantitative vegetation sample plots collected in various efforts.

Sampling Location and Year	Number of Plots
GNP 1999–2000 (VMP; east of the CD)	319
GNP 2000–2002 (VMP; west of the CD)	309
GNP 1999–2001 (Grasslands Ecology Project)	155
WLNP 1999 (VMP)	54
WLNP 1994–1995 (Ecological Land Classification)	276
TOTAL	**1,113**

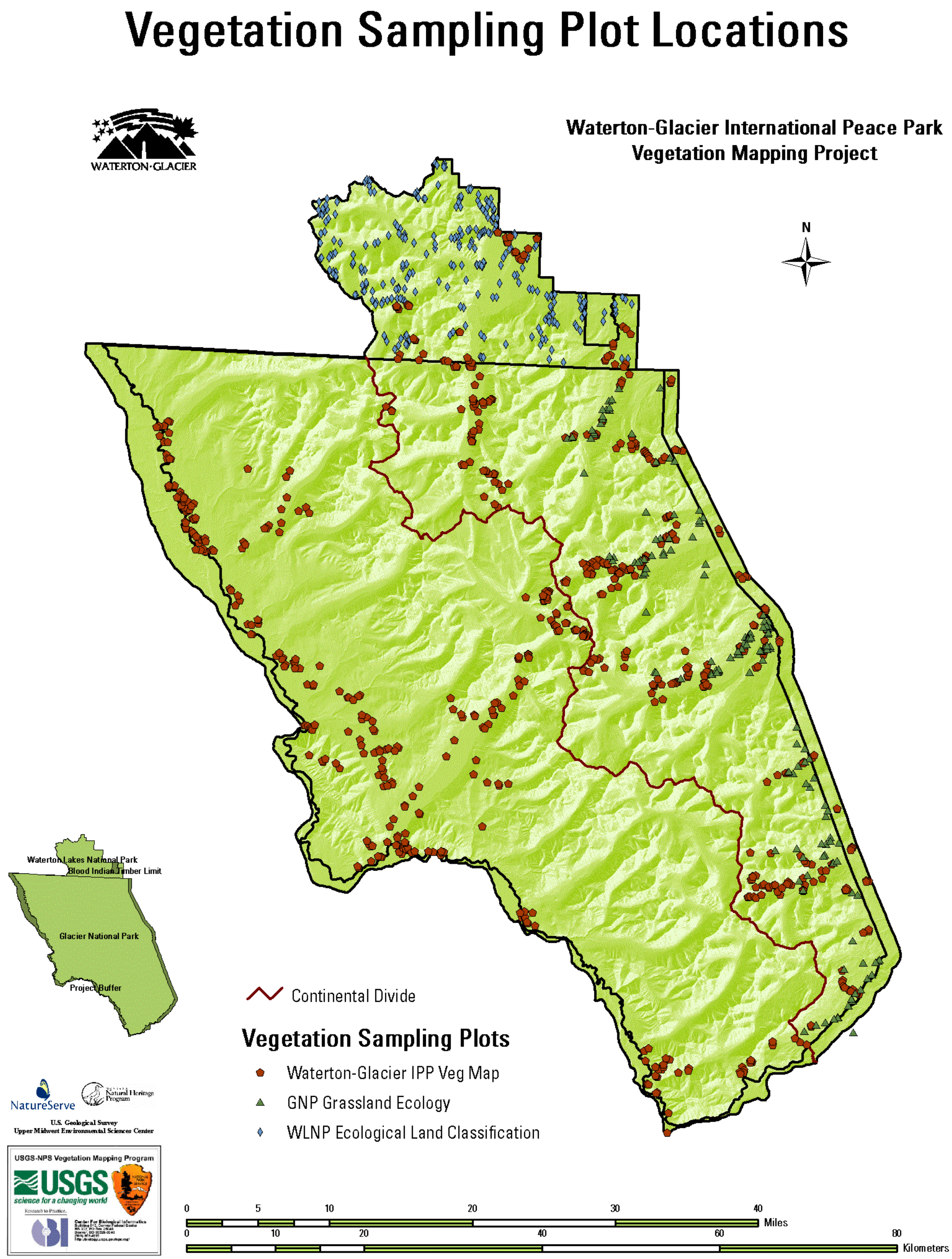

Figure 23. Locations of vegetation sampling plots used for developing the Waterton-Glacier International Peace Park vegetation classification.

Integration of Existing Data Sets

One objective we had with this mapping and classification project was to determine what existing data could be integrated into the classification. Prior to field data collection, we identified a number of existing vegetation data sets and examined them for information regarding vegetation-environment relationships and classification units. These included five separate data sets originally collected for different purposes using different methods:

- Ecological Land Classification of WLNP,
- Alpine Vegetation Study of GNP,
- Grasslands Ecology Project of GNP,
- Whitebark Pine Study of GNP and WLNP, and
- Ecosystem Process Modeling Validation of GNP.

We were able to use each existing data set in drafting the preliminary vegetation classification (as previously discussed; Appendix B). We also used three of the five data sets to help define the final classification, and we used plots from two of the five data sets to complete our quantitative analyses for classification development. Plot requisites for using or incorporating these data sets were (1) accurate georeferencing, (2) canopy cover estimates for all vascular species, and (3) basic abiotic descriptors. Below, we discuss all five data sets and their usability in the final classification development for this project.

Ecological Land Classification of WLNP

The 276 plot data (releves) collected for the development of the Ecological Land Classification (ELC) at WLNP—collected by Achuff et al. (2002a) in 1994–95—were entered into the PLOTS Database System for use in classification analyses. We also incorporated the vegetation types identified with ELC into the Waterton-Glacier IPP vegetation classification matrix. With the additional 54 vegetation sampling plots collected at WLNP for this project (collected in 1999), the combined WLNP vegetation data set totaled 330 plots, which we used in the quantitative analyses for developing the vegetation classification of Waterton-Glacier IPP.

Alpine Vegetation Study of GNP

We used Damm's (2001) alpine vegetation classification of GNP to help round off near-complete delineation of plant associations of Waterton-Glacier IPP. Damm's study also filled a significant gap in the information available on alpine vegetation types of the Northern Rockies—other existing studies are from the alpine of southwestern Montana (Cooper et al. 1997) and further north in Jasper and Kootenay National Parks of Canada (Achuff 1982; Achuff and Dudynsky 1984). Damm's final study consisted of a European phytosociological classification, which is at a much finer scale than the NVC association level concepts. We reviewed Damm's work (630 releves, 3 m x 3 m in size) and found it could be adapted to be in line with NVC concepts. Through qualitative plot and descriptive concept review, a number of his types reclassified into existing NVC types, and others were combined into new NVC associations. See Appendix E: Classification Relationship between Damm and Waterton-Glacier IPP Vegetation Mapping Project for a comparison of Damm's classification and the final NVC associations we recognized for Waterton-Glacier IPP. We used Damm's data and type descriptions to help finalize the vegetation classification of Waterton-Glacier IPP, but we did not use them in the actual quantitative analyses.

Grassland Ecology Project of GNP

Grasslands east of the CD at GNP were sampled for characterizing the extent of weedy species incursion. The 155 vegetation plots from the Grassland Ecology Project at GNP (see the above Vegetation Plot Data Collection section; Shea et al., unpublished data, 2004) were entered into the PLOTS Database System, and were used in the quantitative classification analyses for developing the vegetation classification of Waterton-Glacier IPP.

Whitebark Pine Study of GNP and WLNP / Ecosystem Process Modeling Validation of GNP

In 1995–97, Kendall and Keane (2001) collected 320 plots in GNP and another 14 in WLNP to study whitebark pine (*Pinus albicaulis*). Also, in 1993–95, Robert Keane (U.S. Forest Service, Missoula Fire Laboratory) and Steve Running (University of Montana) collected 173 plots in the Lake McDonald and Saint Mary drainages at GNP for the Ecosystem Process Modeling Validation project. Neither data set contained a complete list of species cover; thus we did not include them in any quantitative analyses, nor use them in descriptions of classified syntaxa.

Qualitative Methods and Draft Vegetation Classification

Prior to quantitative analyses, with the purpose of commencing the vegetation mapping effort, we drafted a vegetation classification based on qualitative review of the vegetation sampling plot data from GNP, WLNP, and the Grassland Ecology Project. We reviewed each plot and assigned a plant association. Our qualitative analysis followed the (1) precepts of the NVC, (2) operating decisions made by a working group of ecologists (particularly with the forests and woodlands), and (3) available keys for associations found in classification reports by Mueggler and Stewart (1980), Hansen et al. (1995) and Cooper et al. (1999).

We first stratified the data by life form according to NVC precepts, and plots were placed into one of five groups:

- Forests and Woodlands,
- Shrublands (including dwarf-shrublands),
- Grasslands,
- Forblands, and
- Sparse Vegetation.

We further subdivided the forest and woodland plots into coniferous, deciduous, and mixed conifer-deciduous canopies. We then further stratified them into vegetation alliances (e.g., *Abies lasiocarpa* Forests, *Populus tremuloides* Forests) following operating principles agreed to by the ecology-working group. Shrub or herb dominated plots were keyed via extant classifications (Mueggler and Stewart 1980; Hansen et al. 1995; Cooper et al. 1999). Worth noting, Mueggler and Stewart (1980) studied primarily rangelands (grasslands), thus requiring our more extensive review of the non-wetland shrub communities. Likewise, these researchers neither concentrated on northwestern mountain grasslands nor on dwarf-shrublands associated with mountainous terrain, thus necessitating our further analysis in this category. Although the Hansen et al. (1995) coverage of wetland and riparian vegetation is statewide, that study benefited from extensive sampling in northwestern Montana, and thus a significant proportion of the vegetation sampling plots we collected in GNP and WLNP keyed easily to existing wetland and riparian NVC types.

Below are some decisions made by the Waterton-Glacier IPP ecology working group regarding classification of stands with forest or woodland structure:

- Existing late-seral (climax) associations must have “appreciable” canopy cover of the late-seral to “climax” tree species (the most shade-tolerant capable of occurring on the site), and the undergrowth meets the association description;
- When seral tree species are dominant, the stand will still be recognized and named according to the most shade-tolerant canopy species with significant representation in the stand (in the following order of decreasing shade tolerance: *Tsuga heterophylla*, *Thuja plicata*, *Abies grandis*,

A. lasiocarpa, *Picea engelmannii*, *Pseudotsuga menziesii*, *Pinus monticola*, *P. albicaulis*, *P. contorta*, *Larix lyallii*, *L. occidentalis*, *P. ponderosa*, *P. flexilis*, deciduous tree species);

- When the upper canopy is a mix of conifer species, and a particular conifer exhibits three times or more relative cover than the next most prevalent conifer—even if the next most prevalent species is more shade-tolerant—the stand will be keyed to the dominant conifer (e.g., if at least 75% cover of *Pinus contorta*, or a ratio of *P. contorta* to *Abies lasiocarpa* cover is 3:1, then the plot will be placed with *P. contorta* forest or woodland);
- When the canopy is a mix of conifer and deciduous tree species, the rules in Table 10 will be followed;
- Undergrowth species will be keyed using the indicator species concepts documented in existing classifications; and
- Where it can be substantiated that the correlation between indicator species and their environment does not hold (or is of little or no value), then the plots will be grouped subjectively using dominance concepts, and their correct assignment to associations will be tested during the quantitative analysis.

Table 10. Rules for forest and woodland classification of mixed conifer and deciduous tree stands.

Type	Relative Proportion (fraction)	Relative Proportion (%)
Coniferous	≥3 times more coniferous than deciduous	≥75% of canopy cover is coniferous
Deciduous	≥3 times more deciduous than coniferous	≥75% of canopy cover is deciduous
Mixed Coniferous and Deciduous	Each canopy type is <3 times as abundant as the other	Each canopy type is >25% and <75% of total cover

Several classifications applicable to the study area (Pfister et al. 1977; Cooper et al. 1987; Hansen et al. 1995) have recognized phases of associations. Phases are not a recognized taxon within the NVC. For most cases, however, we found these phases could actually be recognized as individual associations in the NVC, and we elevated many phases to the association level to capture this additional information (e.g., *Abies lasiocarpa* / *Clintonia uniflora, Menziesia ferruginea* phase became *Abies lasiocarpa* / *Menziesia ferruginea* / *Clintonia uniflora* association; the order of species in the name changed to reflect current NVC nomenclatural convention, listing species by decreasing life form status).

Once we completed the draft classification, we proceeded with map classification development to support the mapping effort. The ecology and mapping teams met several times to discuss the draft vegetation classification and its application in the mapping process.

Semi-final Classification: Quantitative Methods

To develop the near final vegetation classification to be applied in the vegetation mapping, the plot data we assembled from GNP, WLNP, and the Grassland Ecology Project were treated with a variety of quantitative classification and statistical procedures, as discussed below. These algorithms were used to confirm the draft classification, identify misclassifications of individual plots, and formulate appropriate categories to capture those aggregations of species not falling within the existing NVC types. To restate, we did not use Damm’s (2001) study of alpine vegetation in the quantitative analysis, but Damm’s results were incorporated into the final classification. These analyses also gave us insight into community and species response to environmental and disturbance gradients found at Waterton-Glacier IPP.

Data Standardization: Species

We conducted quantitative analyses on the full Waterton-Glacier IPP data set of 1,112 vegetation sampling plots, which previously were entered into the PLOTS Database System (of the original 1,113 plots, one plot was removed from the data set because the species data were not entered, and the original data sheet was lost). The original raw data contained 1,318 taxa, which were concatenated to a common taxonomy (Kartez 1999), and any errors were corrected. Of the original 1,318 entries, 278 taxa were non-vascular, and 132 vascular were eliminated because they were synonyms of other taxa in the database or they were found to be errors. The nonvascular taxa were removed because they were not identified to the species (or even genus) level in most plots. With nonvasculars removed and errors corrected in the data set, the result was 937 species. With the data matrix at this point being quite large (1,112 plots by 937 species) and to reduce ambient noise in the data, all species never occurring with >1% cover (n = 297) were removed from the analyses. This left us with 640 species for quantitative analyses. See Appendix F: Plant Species List of Waterton-Glacier IPP for a full listing of all plant species recognized from both vegetation sampling plots and accuracy assessment (AA) observation plots.

During sampling, species cover was collected by strata. Thus, each tree species occurs three times in the data set: as an upper canopy mature tree, as a lower canopy sapling, and as a seedling. We retained these strata differences during the analysis. Therefore, the 15 tree species in the data set actually span to 45 "pseudo species" in the analysis. Further details on the strata standardization methods are described in Reid et al. (2004). In the summary tables provided in Reid et al. (2004) and in the descriptions provided within this report (Appendix G: Descriptions to Plant Associations of Waterton-Glacier IPP) the corrected raw data were used to present original species and subspecies, along with all tree substrata.

Quantitative Analyses

The full Waterton-Glacier IPP data set was first analyzed together and then broken into distinct subsets for individual analysis. We used PC-ORD software (McCune and Mefford 1999)—a suite of ordination and classification tools—to perform the analyses of vegetation plot data. Conducting quantitative analyses allowed us to identify natural groupings of vegetative characteristics, and helped us define individual associations through similarities in species composition. Agglomerative Cluster Analysis, TWINSPAN, and Nonmetric Multidimensional Scaling (NMS) were performed on the Waterton-Glacier IPP data set for species >1% cover (1,112 plots x 640 species). We performed initial runs of TWINSPAN (Hill 1979) and Cluster Analysis to help break the data into finer levels, and then we reanalyzed the data set using ordination. This process is known as progressive fragmentation (Bridgewater 1989).

In general the classification process followed these steps:

- Run outlier analysis on the data, including subsets, to determine distantly related plots;
- Run presence-absence TWINSPAN to determine general arrangement of species along the gradient of axis 1 in subsequent ordination analyses;
- Run Agglomerative Cluster Analysis to confirm the general variation in arrangement of plots (plots generally held together, showing the same pattern as the TWINSPAN analysis, and the main gradient did not vary);
- Determine the preliminary subsets of the data;
- Compare the provisional, field based community name to each plot within each subset to confirm subgroup membership;
- Develop decision rules for each association and alliance based on conservative group membership; rules are based on review of species cover on a plot-by-plot basis;
- Use decision rules developed in the data to assign plant association names to all data; and
- Use literature review and previously developed plant association concepts to finalize all associations developed from new data.

The Agglomerative Cluster Analysis—based on Euclidian distance and on group average—identified five major groups (subsets):

- Grasslands, Meadows, Alpine, and Dwarf shrublands (356 plots);
- Deciduous and Mixed Deciduous-Coniferous Forests (110 plots);
- Tall Shrublands (167 plots);
- Coniferous Forests (443 plots); and
- Wetlands and Wet Meadows (36 plots).

TWINSPAN and NMS also revealed the same five major groups, or subsections of the data (Figure 24).

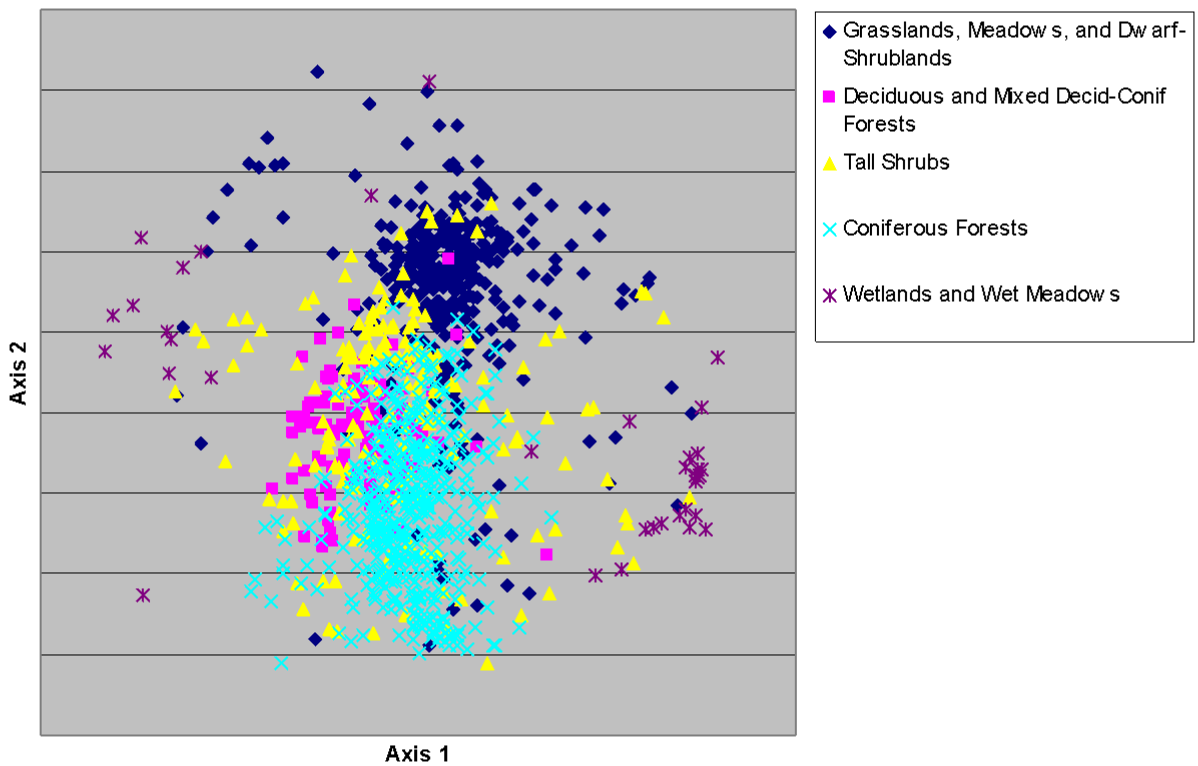

Figure 24. Nonmetric Multidimensional Scaling ordination of vegetation plot data.

Vegetation Plot data consisted of 1,112 plots and 640 species. Five major groups of plots are identified. The Grasslands, Meadows, and Dwarf-shrublands group include alpine communities, and separates from the Coniferous Forests group along axis 2; it can be interpreted as a gradient of cold-dry (at the top) to warm-moist (toward the bottom) environments. The Deciduous and Mixed Deciduous-Coniferous Forests group are near, but still distinct from the Coniferous Forests group. For the Wetlands and Wet Meadows group, the wetlands on the left are colder, subalpine types, while the wetlands on the right are warmer, low elevation types. The Tall Shrub group occurs throughout, as many of their important species are also associated with tree-dominated communities.

We conducted further analysis on each of the five groups to define finer groups of plant associations. For these smaller data subsets, we used Detrended Correspondence Analysis (DCA) ordination (Hill and Gauch 1980). For this part of the analyses, we (1) used the Euclidian distance for similarity, (2) did not downweight rare species, (3) rescaled the axes based on average standard deviation of species turnover, and (4) limited the number of segments to 26.

The Coniferous Forests group was the largest group, with 443 plots (Figure 25). Within this group, a clear gradient of elevation and moisture spread out dissimilar stands (left to right), while samples with similar species composition occupied close ordination space. There were 82 associations described in this group.

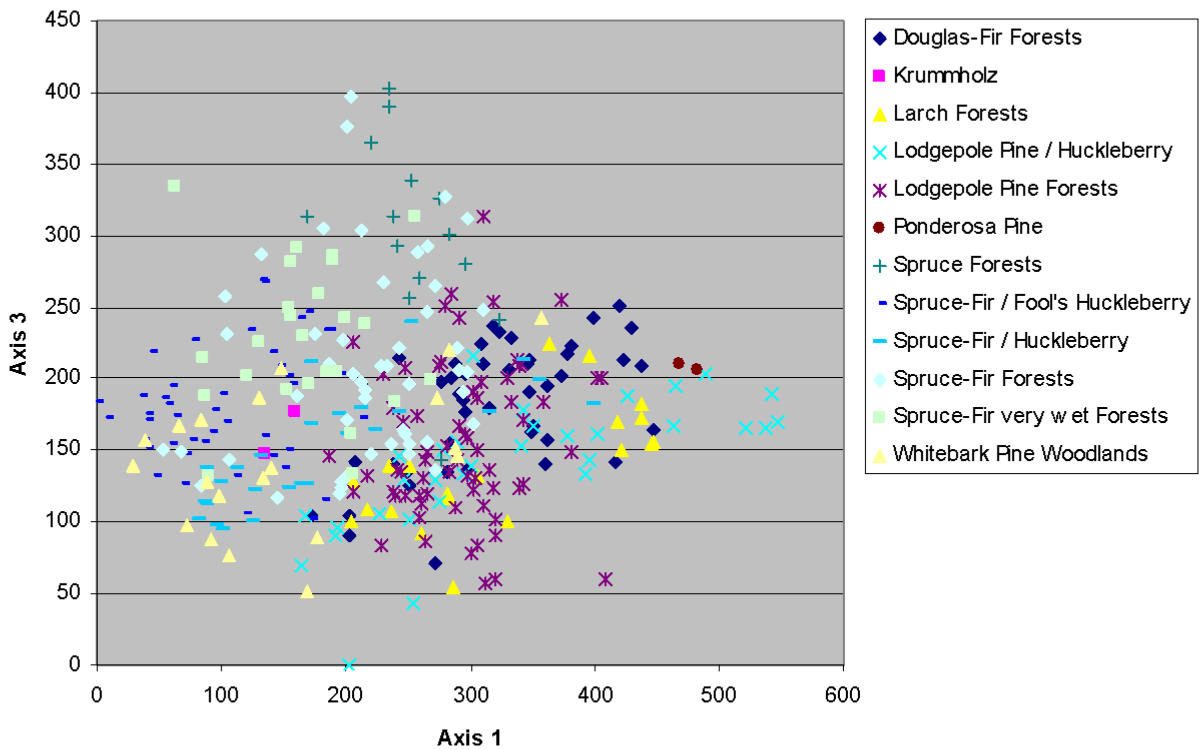

Figure 25. Detrended Correspondence Analysis of the Coniferous Forests group.

This is the Coniferous Forests group shown in Figure 24, consisting of 443 plots. Axis 1 can be inferred to represent elevation, with relatively warmer and lower elevation stands to the right and cooler and higher elevation stands to the left. Ponderosa pine and Douglas-fir types are at lower elevations. The same pattern is repeated for warm and moist larch types, which are located to the right of the whitebark pine woodland types of cooler and drier habitats. The spruce-fir forest types are separated by their various understories (e.g., fools huckleberry occurs at higher, colder elevations). The lodgepole pine forest types occur at slightly lower elevations than spruce-fir forest types.

The Deciduous and Mixed Deciduous-Coniferous Forests group consisted of 110 plots (Figure 26). Within this group, the influence of the understory species is illustrated. While aspen and cottonwood stands are more or less distinct, the moisture loving forb and shrub species dominating the understory obscures the lines, and shows close affiliation with aspen and cottonwood associations. There were 15 associations described in this group.

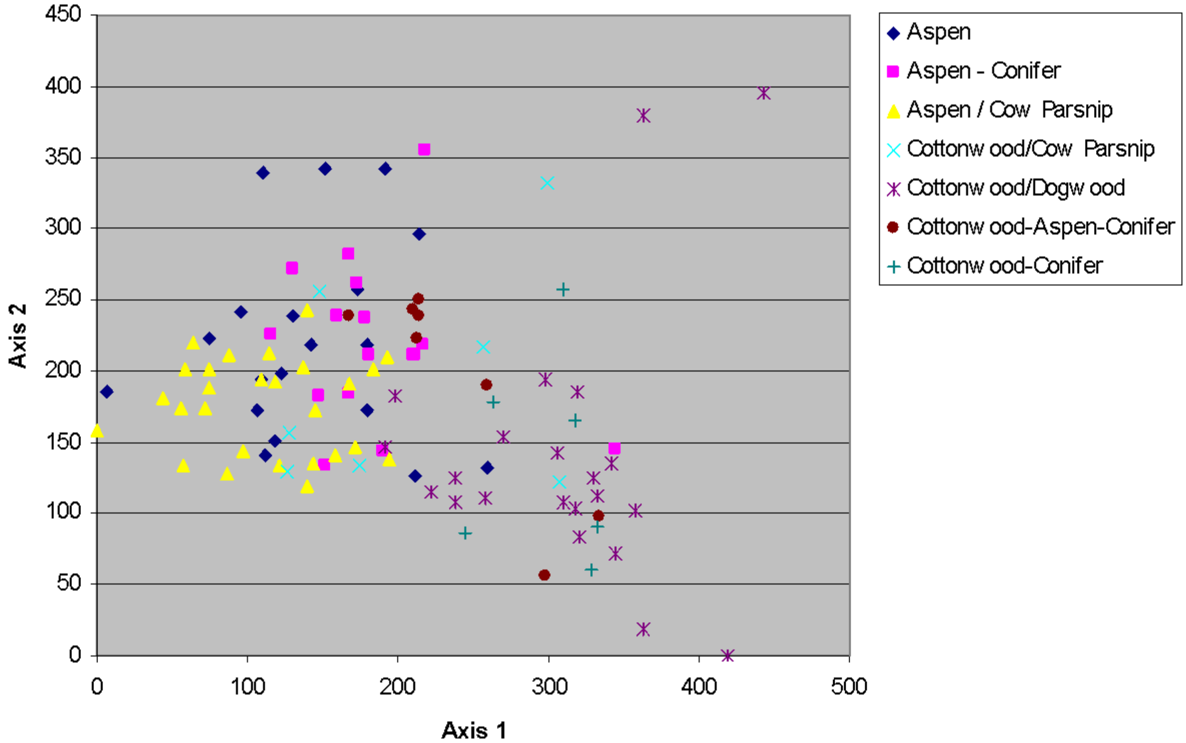

Figure 26. Detrended Correspondence Analysis of the Deciduous and Mixed Deciduous-Coniferous Forests group.

This is the Deciduous and Mixed Deciduous-Coniferous Forests group shown in Figure 24, consisting of 110 plots. Axis 1 can be inferred to represent an elevational gradient, with relatively warmer and lower elevation stands to the right and cooler and higher elevation stands to the left. The aspen forest types usually occur at higher elevations than the cottonwood forest types. Communities with moist understory species (cow parsnip, field horsetail, and red-osier dogwood) are positioned at the lower portion of Axis 2, while communities with slightly drier understory species (serviceberry, snowberry, and queen's cup) occur on higher portions of Axis 2, suggesting this axis represents a moisture gradient.

The Grasslands, Meadows, Alpine, and Dwarf-Shrublands group consisted of 356 plots (Figure 27). Although a large and heterogeneous group, *Festuca* spp. *(F. idahoensis, F. campestris*) were the primary taxa common to many stands in this group. Dry lower-montane fescue grasslands had species common with dry-mesic grasslands of the subalpine, which overlapped with floristic affinities of alpine grasslands and dwarf-shrublands. In addition to grass-dominated stands, several forb-dominated subalpine meadows having grass species components were closely related both in species composition and in geographic proximity to the drier, more exposed grasslands. There were 37 associations described in this group.

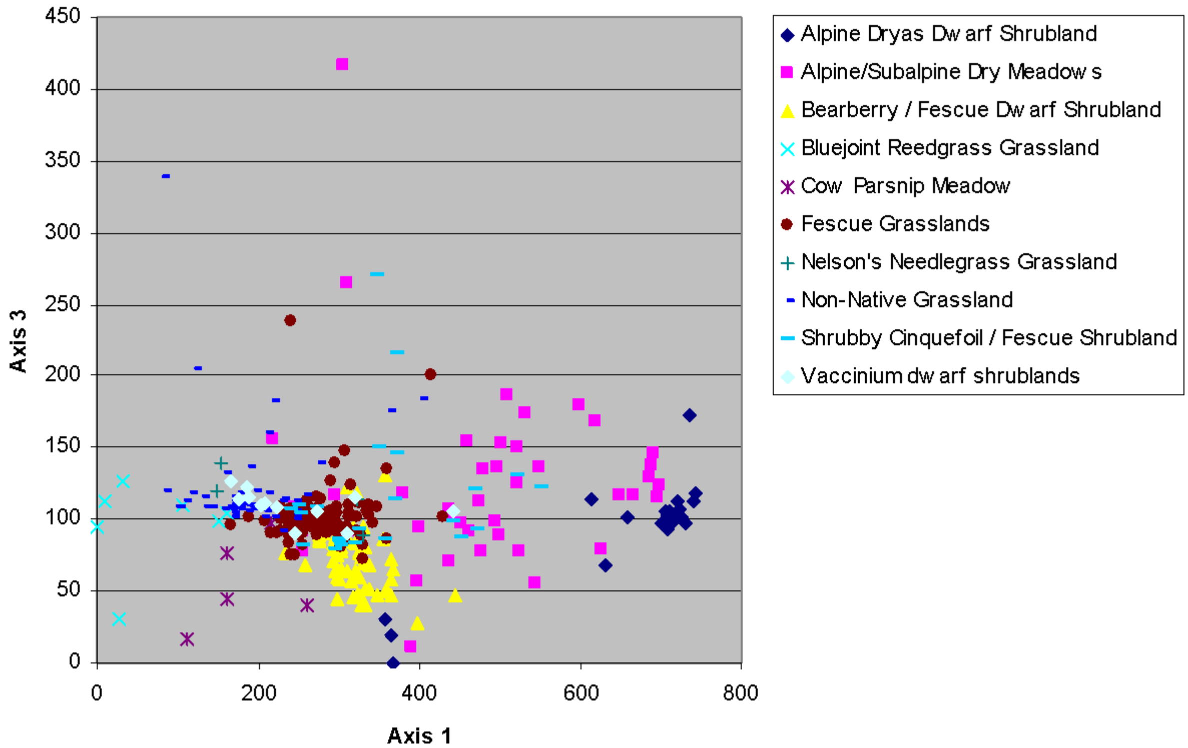

Figure 27. Detrended Correspondence Analysis of the Grasslands, Meadows, Alpine, and Dwarf-shrublands group.

This is the Grasslands, Meadows, Alpine, and Dwarf-shrublands group shown in Figure 24, consisting of 356 plots. In this ordination, there is a clear separation between montane dry fescue grassland types and alpine dryas dwarf-shrubland types. The bluejoint reedgrass types appear as the wettest type at the far left of axis 1. The alpine/subalpine dry meadows represent a number of types, each dominated by different forb species. These meadows are mostly alpine fell-fields, which have slightly lower and warmer micro-climates than alpine dryas dwarf-shrubland types. Fescue grassland types with bearberry are also distinct from fescue grassland types having no shrub component.

While we do not present graphics for the Tall Shrublands (consisting of 167 plots) and the Wetlands and Wet Meadows (consisting of 36 plots), they were treated with the same analytical procedures as the other three groups.

Following ordination of all the subsets, we reviewed each vegetation plot within the context of its group membership. The membership rules were defined by species constancy and cover values, and we used them to construct the semi-final classification. This classification was field-tested in 2002, with subsequent refinements to the plant association field keys (Appendix H: Field Keys to Plant Associations of Waterton-Glacier IPP).

The final plot assignments to associations were based on a subjective review of the data summary tables (presented in Reid et al. 2004), individual plot data, and comparisons to published literature. The previous decisions made by the ecology working group (during draft vegetation classification development) were followed when finalizing the results from the quantitative analyses. Additional rules were defined for membership (e.g., 5% cover of *Oplopanax horridus* is required to assign a plot to one of the Conifer / *Oplopanax* forest associations) of each association. These are illustrated in the plant association field keys (Appendix H). In addition, during the assignment of plots to associations, we considered the context of the range-wide distribution of associations occurring beyond park boundaries.

Following completion of the quantitative analyses, which resulted in a list of plant associations, we compared the list of associations identified from Damm's (2001) alpine study (described above) to the one derived from the quantitative analyses. In a few cases, associations were documented from both the Damm data and from our data, and were combined.

Subsequent Updates to Semi-final Classification

The AA observation plots collected in both GNP and WLNP provided us a plethora of information regarding vegetation types of Waterton-Glacier IPP. The AA data included nearly complete species lists and adequate canopy cover data, allowing us to classify a number of sites without submitting them to quantitative analyses. Some AA sites classified to plant associations documented in the NVC as occurring in Montana, yet were not in the classification developed from the analyses of the plot data. Other sites classified to associations previously undocumented for Montana. Further sites were grouped together for classification into what we termed "park specials." These park special types are local vegetation types, which may occur more widely than GNP or WLNP, and with additional information, could possibly be classified to NVC associations.

We added the associations and park special types found during AA to the semi-final classification list for Waterton-Glacier IPP, and crosswalked the associations to the map classification. In addition, we added the park-special types to the plant association field keys (Appendix H) to more accurately reflect vegetation of Waterton-Glacier IPP.

We then standardized all species nomenclature in the tables for the vegetation sampling plot and AA observation plot data sets to match the present Natural Resources Conservation Service (NRCS) Plants Database standard (USDA NRCS 2004). This was completed for all taxa found in the vegetation sampling plot and AA observation plot data, with revisions documented in the Microsoft Access database described in the Vegetation Classification Products section below.

Results

Final Vegetation Classification

As expected, the Waterton-Glacier IPP proved to be ecologically diverse, with vegetation types ranging from foothill grasslands and woodlands, to high alpine wetlands and fell-fields, to the uniqueness of old-growth cedar-hemlock forests west of the CD. The quantitative analyses of the vegetation sampling plot data, the reworking of the alpine data from Damm (2001), and the qualitative analysis resulted in identifying 198 NVC plant associations[1], and two additional park special communities. Of these associations, 100 were already documented in the NVC; meaning 98 new associations were found during this project. Most plant associations are characterized by indigenous native plants. However, two associations were semi-natural types dominated by nonnative species and/or characterized by anthropogenic disturbances (e.g., *Elymus repens* Semi-natural Herbaceous Vegetation [Provisional] and *Phleum pratense* - *Poa pratensis* - *Bromus inermis* Semi-natural Herbaceous Vegetation). In addition, two associations were designated as provisional, and one additional park-special community was identified in general habitat terms as "early succesional gravel bars."

From the AA observation plot data, we documented an additional 28 NVC associations, and we labeled an additional five types with unique park-special names because they (1) occurred as small patches or stands, (2) were not included in the NVC, and (3) were thought unique to Waterton-Glacier IPP. The two park-special units identified in the semi-final classification were also found during AA. In addition, some

[1] The summary tables (species, strata, and average percent cover) for the 200 plant associations identified from the quantitative analyses are not provided in this report. They can, however, be obtained from Reid et al. (2004).

AA sites represented sparse vegetation of <10% in vascular cover and did not fit any previously described associations. Hence, we grouped these sparse vegetation types into another park-special unit, naming it "undefined sparse vegetation." Of the associations identified with AA observation plot data, three fell into the semi-natural category.

Therefore, the finished version of the final classification—post AA data analysis—lists 226 NVC associations (198 from the semi-final classification and 28 from the AA observation plot data), eight park-special vegetation types (three from the semi-final classification and five from the AA observation plot data), and one more park-special unit containing the group of undefined sparse vegetated types we recognized from AA (Table 11).

Table 11. Plant associations identified at Waterton-Glacier International Peace Park, organized into broad vegetation groups.

Vegetation Groups	Vegetation Types	In GNP	In WLNP
Upland Forests and Woodlands			
Rocky Mountain Subalpine Spruce-Fir Forests	23	21	17
Whitebark Pine and Subalpine Larch Woodlands	8	8	5
Rocky Mountain Lodgepole Pine Forests	17	16	11
Dry-Mesic Montane Mixed Conifer Forests	15	15	9
Western Red Cedar - Hemlock Forests	7	7	0
Ponderosa Pine Woodlands	3	3	0
Limber Pine Woodlands	4	4	1
Western Larch Forests	5	5	0
Aspen, Birch, and Black Cottonwood Forests	10	9	6
Mixed Deciduous - Coniferous Forests	5	5	3
Wetland and Riparian Forests			
Coniferous Forests	13	13	4
Deciduous and Mixed Forests	7	7	6
Upland Shrublands and Herbaceous			
Alpine - Upper Subalpine Shrub and Herbaceous	25	25	11
Montane and Foothill Upland Shrublands	24	24	14
Montane Grasslands and Meadows	18	17	10
Wetland and Riparian Shrublands and Herbaceous			
Wetland and Riparian Shrublands	26	23	11
Herbaceous Wetlands	24	20	14
Totals	**234**	**222**	**122**

Note: the undefined sparse vegetation, a park-special unit, is not included in the above count.

Vegetation Classification Products

Vegetation Classification and Plant Association Descriptions

Table 12 lists the final vegetation classification for the Waterton-Glacier IPP Vegetation Mapping Project and is organized according to the 1997 version of the NVC physiognomic hierarchy (FGDC 1997). Appendix I: Final Vegetation Classification of Waterton-Glacier IPP provides a similar listing of these plant associations with the addition of vegetation sampling plot data, AA observation plot data, and global and state rankings listed for each community.

Table 12. Final vegetation classification for the Waterton-Glacier International Peace Park Vegetation Mapping Project.

Class	Subclass	Alliance	CEGL Code	Association Name
Forest				
	Evergreen forest			
		Abies lasiocarpa - Picea engelmannii Forest Alliance		
			CEGL000294	Abies lasiocarpa - Picea engelmannii / Acer glabrum Forest
			CEGL000311	Abies lasiocarpa - Picea engelmannii / Galium triflorum Forest
			CEGL000315	Abies lasiocarpa - Picea engelmannii / Linnaea borealis Forest
			CEGL000340	Abies lasiocarpa - Picea engelmannii / Vaccinium caespitosum Forest
			CEGL005892	Abies lasiocarpa - Picea engelmannii / Clintonia uniflora - Xerophyllum tenax Forest
			CEGL005893	Abies lasiocarpa - Picea engelmannii / Menziesia ferruginea / Clintonia uniflora Forest
			CEGL005894	Abies lasiocarpa - Picea engelmannii / Menziesia ferruginea - Vaccinium scoparium Forest
			CEGL005895	Abies lasiocarpa - Picea engelmannii / Menziesia ferruginea / Xerophyllum tenax Forest
			CEGL005912	Abies lasiocarpa - Picea engelmannii / Clintonia uniflora Forest
			CEGL005914	Abies lasiocarpa - Picea engelmannii / Vaccinium scoparium / Xerophyllum tenax Forest
			CEGL005917	Abies lasiocarpa - Picea engelmannii / Vaccinium membranaceum / Xerophyllum tenax Forest
			CEGL005918	Abies lasiocarpa - Picea engelmannii / Vaccinium caespitosum / Clintonia uniflora Forest
			CEGL005919	Abies lasiocarpa - Picea engelmannii / Vaccinium scoparium / Thalictrum occidentale Forest
		Picea engelmannii Forest Alliance		
			CEGL005925	Picea engelmannii / Juniperus communis Forest
			CEGL005926	Picea engelmannii / Vaccinium caespitosum Forest
		Pinus contorta Forest Alliance		
			CEGL000135	Pinus contorta / Arnica cordifolia Forest
			CEGL000139	Pinus contorta / Calamagrostis rubescens Forest
			CEGL000153	Pinus contorta / Linnaea borealis Forest
			CEGL000164	Pinus contorta / Spiraea betulifolia Forest
			CEGL000168	Pinus contorta / Vaccinium caespitosum Forest
			CEGL000172	Pinus contorta / Vaccinium scoparium Forest
			CEGL000174	Pinus contorta / Vaccinium scoparium / Calamagrostis rubescens Forest
			CEGL005913	Pinus contorta / Vaccinium membranaceum / Xerophyllum tenax Forest
			CEGL005916	Pinus contorta / Clintonia uniflora Forest
			CEGL005922	Pinus contorta / Menziesia ferruginea / Clintonia uniflora Forest

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL005923	Pinus contorta / Vaccinium caespitosum / Clintonia uniflora Forest
			CEGL005924	Pinus contorta / Vaccinium scoparium / Xerophyllum tenax Forest
			CEGL005928	Pinus contorta / Menziesia ferruginea Forest
			Park Special 8	Pinus contorta / Acer glabrum Forest
			Park Special 9	Pinus contorta / Menziesia ferruginea / Xerophyllum tenax Forest
		Pinus ponderosa Forest Alliance		
			CEGL000203	Pinus ponderosa / Symphoricarpos albus Forest
		Pseudotsuga menziesii Forest Alliance		
			CEGL000418	Pseudotsuga menziesii / Acer glabrum Forest
			CEGL000424	Pseudotsuga menziesii / Arctostaphylos uva-ursi Forest
			CEGL000427	Pseudotsuga menziesii / Arnica cordifolia Forest
			CEGL000430	Pseudotsuga menziesii / Carex geyeri Forest
			CEGL000439	Pseudotsuga menziesii / Juniperus communis Forest
			CEGL000457	Pseudotsuga menziesii / Spiraea betulifolia Forest
			CEGL000459	Pseudotsuga menziesii / Symphoricarpos albus Forest
			CEGL000465	Pseudotsuga menziesii / Vaccinium caespitosum Forest
			CEGL005850	Pseudotsuga menziesii / Clintonia uniflora Forest
			CEGL005851	Pseudotsuga menziesii / Menziesia ferruginea / Clintonia uniflora Forest
			CEGL005852	Pseudotsuga menziesii / Vaccinium membranaceum / Xerophyllum tenax Forest
			CEGL005853	Pseudotsuga menziesii / Heracleum maximum Forest
			CEGL005854	Pseudotsuga menziesii / Clintonia uniflora - Xerophyllum tenax Forest
		Thuja plicata Forest Alliance		
			CEGL000471	Thuja plicata / Aralia nudicaulis Forest
			CEGL000474	Thuja plicata / Clintonia uniflora Forest
			CEGL000476	Thuja plicata / Gymnocarpium dryopteris Forest
			CEGL005930	Thuja plicata / Clintonia uniflora - Xerophyllum tenax Forest
			CEGL005931	Thuja plicata / Carex disperma Forest [Provisional]
		Tsuga heterophylla Forest Alliance		
			CEGL000488	Tsuga heterophylla / Aralia nudicaulis Forest
			CEGL000493	Tsuga heterophylla / Clintonia uniflora Forest
			CEGL000494	Tsuga heterophylla / Gymnocarpium dryopteris Forest

Class	Subclass	Alliance	CEGL Code	Association Name
	Deciduous forest			
		Larix occidentalis Forest Alliance		
			CEGL005880	Larix occidentalis / Clintonia uniflora Forest
			CEGL005881	Larix occidentalis / Clintonia uniflora - Xerophyllum tenax Forest
			CEGL005882	Larix occidentalis / Vaccinium caespitosum Forest
			CEGL005883	Larix occidentalis / Vaccinium caespitosum / Clintonia uniflora Forest
			Park Special 7	Larix occidentalis / Linnaea borealis Forest
		Populus tremuloides Forest Alliance		
			CEGL000575	Populus tremuloides / Calamagrostis rubescens Forest
			CEGL000595	Populus tremuloides / Heracleum maximum Forest
			CEGL000602	Populus tremuloides / Rubus parviflorus Forest
			CEGL000607	Populus tremuloides / Spiraea betulifolia Forest
			CEGL000609	Populus tremuloides / Symphoricarpos albus Forest
			CEGL003748	Populus tremuloides / Invasive Perennial Grasses Forest
			CEGL005848	Populus tremuloides / Symphoricarpos occidentalis Forest [Provisional]
			CEGL005849	Populus tremuloides / Urtica dioica Forest [Provisional]
			CEGL005911	Populus tremuloides - Conifer / Spiraea betulifolia - Symphoricarpos albus Forest
	Mixed evergreen-deciduous forest			
		Abies lasiocarpa - Populus tremuloides Forest Alliance		
			CEGL005908	Populus tremuloides - Abies lasiocarpa - Picea engelmannii / Streptopus amplexifolius Forest
		Populus balsamifera ssp. trichocarpa Temporarily Flooded Forest Alliance		
			CEGL000542	Populus balsamifera ssp. trichocarpa - (Populus tremuloides) / Heracleum maximum Forest
			CEGL005906	Populus balsamifera ssp. trichocarpa - Populus tremuloides - Conifer / Clintonia uniflora Forest
			CEGL005910	Populus balsamifera ssp. trichocarpa - Populus tremuloides - Conifer / Heracleum maximum Forest
Woodland				
	Evergreen woodland			
		Abies lasiocarpa Woodland Alliance		
			CEGL000317	Abies lasiocarpa - Picea engelmannii / Luzula glabrata var. hitchcockii Woodland
			CEGL005823	Abies lasiocarpa - Picea engelmannii / Valeriana sitchensis Woodland
			CEGL005896	Abies lasiocarpa - Picea engelmannii / Menziesia ferruginea / Luzula glabrata var. hitchcockii Woodland
			CEGL005897	Abies lasiocarpa - Picea engelmannii / Menziesia ferruginea / Streptopus amplexifolius Woodland

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL005898	Abies lasiocarpa - Picea engelmannii / Xerophyllum tenax - Luzula glabrata var. hitchcockii Woodland
			CEGL005920	Abies lasiocarpa - Picea engelmannii / Streptopus amplexifolius - Luzula glabrata var. hitchcockii Woodland
		Pinus albicaulis - Abies lasiocarpa Woodland Alliance		
			CEGL005836	Pinus albicaulis - Abies lasiocarpa / Menziesia ferruginea / Xerophyllum tenax Woodland
			CEGL005837	Pinus albicaulis - Abies lasiocarpa / Vaccinium membranaceum / Xerophyllum tenax Woodland
			CEGL005838	Pinus albicaulis - Abies lasiocarpa / Vaccinium scoparium / Xerophyllum tenax Woodland
			CEGL005839	Pinus albicaulis - Abies lasiocarpa / Vaccinium scoparium / Luzula glabrata var. hitchcockii Woodland
		Pinus albicaulis Woodland Alliance		
			CEGL000128	Pinus albicaulis - Abies lasiocarpa Woodland
			CEGL000754	Pinus albicaulis - (Abies lasiocarpa) / Carex geyeri Woodland
			CEGL005840	Pinus albicaulis - (Picea engelmannii) / Dryas octopetala Woodland
		Pinus contorta Woodland Alliance		
			CEGL000764	Pinus contorta / Juniperus communis Woodland
			CEGL005915	Pinus contorta / Heracleum maximum Woodland
			CEGL005921	Pinus contorta / Clintonia uniflora - Xerophyllum tenax Woodland
		Pinus flexilis Woodland Alliance		
			CEGL000802	Pinus flexilis / Arctostaphylos uva-ursi Woodland
			CEGL000805	Pinus flexilis / Festuca idahoensis Woodland
			CEGL000806	Pinus flexilis / Festuca campestris Woodland
			CEGL000807	Pinus flexilis / Juniperus communis Woodland
		Pinus ponderosa Woodland Alliance		
			CEGL000185	Pinus ponderosa / Festuca campestris Woodland
			CEGL005841	Pinus ponderosa / Vaccinium caespitosum Woodland
		Pseudotsuga menziesii Woodland Alliance		
			CEGL000429	Pseudotsuga menziesii / Calamagrostis rubescens Woodland
			CEGL000900	Pseudotsuga menziesii / Festuca idahoensis Woodland
	Deciduous woodland			
		Betula papyrifera Woodland Alliance		
			CEGL005844	Betula papyrifera / Acer glabrum Woodland
			CEGL005904	Betula papyrifera - Conifer / Clintonia uniflora Woodland
		Larix lyallii Woodland Alliance		

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL005884	Larix lyallii / Vaccinium membranaceum / Luzula glabrata var. hitchcockii Woodland
Riparian and swamp forest and woodland				
	Conifer riparian and swamp forest and woodland			
		Abies lasiocarpa Seasonally Flooded Forest Alliance		
			CEGL000300	Abies lasiocarpa - Picea engelmannii / Calamagrostis canadensis Forest
			CEGL000322	Abies lasiocarpa - Picea engelmannii / Oplopanax horridus Forest
		Abies lasiocarpa Temporarily Flooded Forest Alliance		
			CEGL000297	Abies lasiocarpa - Picea engelmannii / Alnus viridis ssp. sinuata Forest
			CEGL000336	Abies lasiocarpa - Picea engelmannii / Streptopus amplexifolius Forest
		Picea engelmannii Seasonally Flooded Forest Alliance		
			CEGL005927	Picea engelmannii / Equisetum arvense Forest
		Picea engelmannii Seasonally Flooded Woodland Alliance		
			CEGL005843	Picea engelmannii / Salix drummondiana Woodland
		Picea engelmannii Temporarily Flooded Woodland Alliance		
			CEGL002677	Picea engelmannii / Cornus sericea Woodland
		Pinus contorta Seasonally Flooded Forest Alliance		
			CEGL000138	Pinus contorta / Calamagrostis canadensis Forest
		Pinus contorta Temporarily Flooded Woodland Alliance		
			CEGL005929	Pinus contorta / Cornus sericea Woodland
		Pseudotsuga menziesii Temporarily Flooded Woodland Alliance		
			CEGL000899	Pseudotsuga menziesii / Cornus sericea Woodland
		Thuja plicata Seasonally Flooded Forest Alliance		
			CEGL000473	Thuja plicata / Athyrium filix-femina Forest
			CEGL000479	Thuja plicata - Tsuga heterophylla / Oplopanax horridus Rocky Mountain Forest
		Tsuga heterophylla Temporarily Flooded Forest Alliance		
			CEGL000491	Tsuga heterophylla / Athyrium filix-femina Forest
	Deciduous and mixed riparian and swamp forest and woodland			
		Populus balsamifera ssp. trichocarpa Temporarily Flooded Forest Alliance		
			CEGL000672	Populus balsamifera ssp. trichocarpa / Cornus sericea Forest
			CEGL005845	Populus balsamifera ssp. trichocarpa / Calamagrostis canadensis Forest [Provisional]
			CEGL005905	Populus balsamifera ssp. trichocarpa - Populus tremuloides - Conifer / Cornus sericea Forest

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL005907	Populus balsamifera ssp. trichocarpa - Picea engelmannii / Equisetum arvense Forest
			CEGL005909	Populus balsamifera ssp. trichocarpa - Populus tremuloides - Conifer / Calamagrostis canadensis Forest
		Populus tremuloides Temporarily Flooded Forest Alliance		
			CEGL000582	Populus tremuloides / Cornus sericea Forest
		Populus tremuloides Seasonally Flooded Forest Alliance		
			CEGL000574	Populus tremuloides / Calamagrostis canadensis Forest
Shrubland				
	Evergreen shrubland			
		Abies lasiocarpa - Picea engelmannii - Pinus flexilis Krummholz Shrubland Alliance		
			CEGL000985	Abies lasiocarpa - Picea engelmannii Krummholz Shrubland
	Deciduous shrubland			
		Acer glabrum Shrubland Alliance		
			CEGL001061	Acer glabrum Avalanche Chute Shrubland
		Amelanchier alnifolia Shrubland Alliance		
			CEGL001065	Amelanchier alnifolia / Pseudoroegneria spicata - Bunchgrass Shrubland
			CEGL005885	Amelanchier alnifolia / (Mixed Grass, Forb) Shrubland
			CEGL005886	Populus tremuloides / Amelanchier alnifolia Avalanche Chute Shrubland
		Menziesia ferruginea Shrubland Alliance		
			CEGL005888	Menziesia ferruginea / Xerophyllum tenax Shrubland
		Prunus virginiana Shrubland Alliance		
			CEGL001108	Prunus virginiana - (Prunus americana) Shrubland
		Rubus parviflorus Shrubland Alliance		
			CEGL001127	Rubus parviflorus / Chamerion angustifolium - Heracleum maximum Shrubland
		Spiraea betulifolia Shrubland Alliance		
			CEGL005835	Spiraea betulifolia Shrubland
		Symphoricarpos albus Shrubland Alliance		
			CEGL005890	Symphoricarpos albus Shrubland
		Symphoricarpos occidentalis Temporarily Flooded Shrubland Alliance		
			CEGL001131	Symphoricarpos occidentalis Shrubland
		Undescribed Alliance		
			Park Special 6	Salix scouleriana Shrubland

Class	Subclass	Alliance	CEGL Code	Association Name
		Vaccinium membranaceum Shrubland Alliance		
			CEGL005891	Vaccinium membranaceum / Xerophyllum tenax Shrubland
Dwarf-shrubland				
	Evergreen dwarf-shrubland			
		Arctostaphylos uva-ursi Dwarf-shrubland Alliance		
			CEGL005830	Arctostaphylos uva-ursi / Festuca campestris - Festuca idahoensis Dwarf-shrubland
			CEGL005831	Arctostaphylos uva-ursi / Pseudoroegneria spicata Dwarf-shrubland
			CEGL005832	Arctostaphylos uva-ursi / Solidago multiradiata Dwarf-shrubland
		Dryas drummondii Dwarf-shrubland Alliance		
			CEGL005834	Dryas drummondii / Chamerion latifolium Dwarf-shrubland
		Phyllodoce glanduliflora Dwarf-shrubland Alliance		
			CEGL005877	Phyllodoce glanduliflora / Sibbaldia procumbens Dwarf-shrubland
	Deciduous dwarf-shrubland			
		Salix arctica Dwarf-shrubland Alliance		
			CEGL001431	Salix arctica - (Salix petrophila, Salix nivalis) / Polygonum bistortoides Dwarf-shrubland
			CEGL005878	Salix arctica / Carex nigricans Dwarf-shrubland
		Vaccinium (caespitosum, myrtillus, scoparium) Dwarf-shrubland Alliance		
			CEGL005879	Vaccinium (myrtillus, scoparium) / Luzula glabrata var. hitchcockii Dwarf-shrubland
Riparian and wetland shrubland				
		Alnus incana Temporarily Flooded Shrubland Alliance		
			CEGL001141	Alnus incana Shrubland
			CEGL001143	Alnus incana / Calamagrostis canadensis Shrubland
			CEGL001145	Alnus incana / Cornus sericea Shrubland
		Alnus viridis ssp. sinuata Temporarily Flooded Shrubland Alliance		
			CEGL001156	Alnus viridis ssp. sinuata / Athyrium filix-femina - Cinna latifolia Shrubland
			CEGL002633	Alnus viridis ssp. sinuata / Mesic Forbs Shrubland
		Betula nana Seasonally Flooded Shrubland Alliance		
			CEGL001079	Betula nana / Carex utriculata Shrubland
			CEGL005887	Betula nana / Carex spp. Shrubland
		Betula occidentalis Seasonally Flooded Shrubland Alliance		
			CEGL001080	Betula occidentalis Shrubland

Class	Subclass	Alliance	CEGL Code	Association Name
		Cornus sericea Temporarily Flooded Shrubland Alliance		
			CEGL001165	Cornus sericea Shrubland
		Crataegus (douglasii, succulenta) Temporarily Flooded Shrubland Alliance		
			CEGL001093	Crataegus douglasii - (Crataegus chrysocarpa) Shrubland
		Elaeagnus commutata Temporarily Flooded Shrubland Alliance		
			CEGL001098	Elaeagnus commutata Shrubland
		Kalmia microphylla Saturated Dwarf-shrubland Alliance		
			CEGL001402	Kalmia microphylla / Carex nigricans Dwarf-shrubland
		Rhamnus alnifolia Temporarily Flooded Shrubland Alliance		
			CEGL001132	Rhamnus alnifolia Shrubland
		Ribes lacustre Temporarily Flooded Shrubland Alliance		
			CEGL005889	Ribes lacustre / Chamerion angustifolium Shrubland [Provisional]
		Rosa woodsii Temporarily Flooded Shrubland Alliance		
			CEGL001126	Rosa woodsii Shrubland
		Salix bebbiana Temporarily Flooded Shrubland Alliance		
			CEGL001173	Salix bebbiana Shrubland
		Salix boothii Seasonally Flooded Shrubland Alliance		
			CEGL001175	Salix boothii / Calamagrostis canadensis Shrubland
		Salix boothii Temporarily Flooded Shrubland Alliance		
			CEGL001178	Salix boothii / Carex utriculata Shrubland
			CEGL001180	Salix boothii / Mesic Forbs Shrubland
		Salix commutata Seasonally Flooded Shrubland Alliance		
			CEGL003497	Salix commutata / Mesic Graminoid Shrubland
		Salix drummondiana Seasonally Flooded Shrubland Alliance		
			CEGL002631	Salix drummondiana / Carex utriculata Shrubland
		Salix drummondiana Temporarily Flooded Shrubland Alliance		
			CEGL001192	Salix drummondiana / Mesic Forbs Shrubland
			CEGL002667	Salix drummondiana / Calamagrostis canadensis Shrubland
		Salix (exigua, interior) Temporarily Flooded Shrubland Alliance		
			CEGL001199	Salix exigua / Agrostis stolonifera Shrubland
		Salix geyeriana Temporarily Flooded Shrubland Alliance		

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL002666	Salix geyeriana / Mesic Forbs Shrubland
		Salix glauca Temporarily Flooded Shrubland Alliance		
			CEGL001136	Salix glauca Shrubland
		Undescribed Alliance		
			Park Special 1	Gravel Bar Early Successional Vegetation
			Park Special 4	Salix pseudomonticola Shrubland
Herbaceous Vegetation				
	Perennial graminoid vegetation			
		Achnatherum nelsonii Herbaceous Alliance		
			CEGL005860	Achnatherum nelsonii - Lupinus sericeus Herbaceous Vegetation
		Calamagrostis rubescens Herbaceous Alliance		
			CEGL005862	Calamagrostis rubescens Herbaceous Vegetation
		Carex geyeri Herbaceous Alliance		
			CEGL005864	Carex geyeri Herbaceous Vegetation
		Carex paysonis Herbaceous Alliance		
			CEGL005865	Carex paysonis - Sibbaldia procumbens Herbaceous Vegetation
		Carex albonigra Herbaceous Alliance		
			CEGL005863	Carex albonigra - Myosotis asiatica Herbaceous Vegetation
		Carex scirpoidea Herbaceous Alliance		
			CEGL005866	Carex scirpoidea - Zigadenus elegans Herbaceous Vegetation
		Carex spectabilis Herbaceous Alliance		
			CEGL005867	Carex spectabilis - Arnica X diversifolia Herbaceous Vegetation
		Elymus repens Herbaceous Alliance		
			CEGL005868	Elymus repens Semi-natural Herbaceous Vegetation
		Festuca campestris Herbaceous Alliance		
			CEGL005875	Festuca campestris - Festuca idahoensis Herbaceous Vegetation
			CEGL001629	Festuca campestris - Pseudoroegneria spicata Herbaceous Vegetation
		Festuca idahoensis Alpine Herbaceous Alliance		
			CEGL001623	Festuca idahoensis - (Festuca campestris) / Potentilla diversifolia Herbaceous Vegetation
		Festuca idahoensis Herbaceous Alliance		
			CEGL001614	Festuca idahoensis - Elymus trachycaulus Herbaceous Vegetation

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL001624	Festuca idahoensis - Pseudoroegneria spicata Herbaceous Vegetation
			CEGL001625	Festuca idahoensis - Achnatherum richardsonii Herbaceous Vegetation
			CEGL001898	Festuca idahoensis - Carex filifolia Herbaceous Vegetation
			CEGL005869	Festuca campestris - (Festuca idahoensis) - Achnatherum richardsonii Herbaceous Vegetation
			CEGL005870	Festuca campestris - Festuca idahoensis - Geranium viscosissimum Herbaceous Vegetation
		Juncus parryi Herbaceous Alliance		
			CEGL005871	Juncus parryi / Sibbaldia procumbens Herbaceous Vegetation
		Kobresia myosuroides Herbaceous Alliance		
			CEGL005872	Kobresia myosuroides - Euphrasia disjuncta Herbaceous Vegetation
		Luzula glabrata var. hitchcockii Herbaceous Alliance		
			CEGL005873	Luzula glabrata var. hitchcockii - Erythronium grandiflorum Herbaceous Vegetation
		Poa pratensis Semi-natural Herbaceous Alliance		
			CEGL005874	Phleum pratense - Poa pratensis - Bromus inermis Semi-natural Herbaceous Vegetation
		Pseudoroegneria spicata Herbaceous Alliance		
			CEGL001677	Pseudoroegneria spicata - Poa secunda Herbaceous Vegetation
			CEGL005861	Bromus marginatus - Pseudoroegneria spicata Herbaceous Vegetation [Provisional]
	Shrub-steppe (temperate or subpolar grassland with a sparse shrub layer)			
		Artemisia tridentata ssp. vaseyana Shrub Herbaceous Alliance		
			CEGL001531	Artemisia tridentata ssp. vaseyana / Festuca campestris Shrub Herbaceous Vegetation
			CEGL001533	Artemisia tridentata ssp. vaseyana / Festuca idahoensis Shrub Herbaceous Vegetation
		Dasiphora fruticosa ssp. floribunda Shrub Herbaceous Alliance		
			CEGL001502	Dasiphora fruticosa ssp. floribunda / Festuca idahoensis Shrub Herbaceous Vegetation
			CEGL001503	Dasiphora fruticosa ssp. floribunda / Festuca campestris Shrub Herbaceous Vegetation
			CEGL005833	Dasiphora fruticosa ssp. floribunda / Artemisia michauxiana Shrub Herbaceous Vegetation [Provisional]
		Dryas octopetala Dwarf-shrub Herbaceous Alliance		
			CEGL001892	Dryas octopetala - Carex rupestris Dwarf-shrub Herbaceous Vegetation
			CEGL001894	Dryas octopetala - Polygonum viviparum Dwarf-shrub Herbaceous Vegetation
	Perennial forb vegetation			
		Arenaria capillaris Herbaceous Alliance		
			CEGL005855	Arenaria capillaris / Polytrichum piliferum Herbaceous Vegetation
		Chamerion angustifolium Herbaceous Alliance		

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL005856	Chamerion angustifolium Rocky Mountain Herbaceous Vegetation [Provisional]
		Valeriana sitchensis Herbaceous Alliance		
			CEGL001998	Valeriana sitchensis - Veratrum viride Herbaceous Vegetation
		Xerophyllum tenax Herbaceous Alliance		
			CEGL005859	Xerophyllum tenax Herbaceous Vegetation
Herbaceous Wetlands				
	Graminoid herbaceous wetland			
		Calamagrostis canadensis Seasonally Flooded Herbaceous Alliance		
			CEGL001559	Calamagrostis canadensis Western Herbaceous Vegetation
		Carex (rostrata, utriculata) Seasonally Flooded Herbaceous Alliance		
			CEGL001562	Carex utriculata Herbaceous Vegetation
		Carex aquatilis Seasonally Flooded Herbaceous Alliance		
			CEGL001802	Carex aquatilis Herbaceous Vegetation
			CEGL001803	Carex aquatilis - Carex utriculata Herbaceous Vegetation
		Carex atherodes Seasonally Flooded Herbaceous Alliance		
			CEGL002220	Carex atherodes Herbaceous Vegetation
		Carex buxbaumii Seasonally Flooded Herbaceous Alliance		
			CEGL001806	Carex buxbaumii Herbaceous Vegetation
		Carex lasiocarpa Seasonally Flooded Herbaceous Alliance		
			CEGL001810	Carex lasiocarpa Herbaceous Vegetation
		Carex limosa Seasonally Flooded Herbaceous Alliance		
			CEGL001811	Carex limosa Herbaceous Vegetation
		Carex microptera Seasonally Flooded Herbaceous Alliance		
			CEGL001792	Carex microptera Herbaceous Vegetation
		Carex nigricans Seasonally Flooded Herbaceous Alliance		
			CEGL005824	Carex nigricans - Sibbaldia procumbens Herbaceous Vegetation
		Carex vesicaria Seasonally Flooded Herbaceous Alliance		
			CEGL002661	Carex vesicaria Herbaceous Vegetation
		Deschampsia caespitosa Seasonally Flooded Herbaceous Alliance		
			CEGL001599	Deschampsia caespitosa Herbaceous Vegetation
		Dulichium arundinaceum Seasonally Flooded Herbaceous Alliance		

Class	Subclass	Alliance	CEGL Code	Association Name
			CEGL001831	Dulichium arundinaceum Seasonally Flooded Herbaceous Vegetation
		Eleocharis palustris Seasonally Flooded Herbaceous Alliance		
			CEGL001833	Eleocharis palustris Herbaceous Vegetation
		Juncus balticus Seasonally Flooded Herbaceous Alliance		
			CEGL001838	Juncus balticus Herbaceous Vegetation
		Phalaris arundinacea Seasonally Flooded Herbaceous Alliance		
			CEGL001474	Phalaris arundinacea Western Herbaceous Vegetation
		Poa palustris Semi-natural Seasonally Flooded Herbaceous Alliance		
			CEGL001659	Poa palustris Herbaceous Vegetation
		Schoenoplectus acutus - (Schoenoplectus tabernaemontani) Semipermanently Flooded Herbaceous Alliance		
			CEGL002623	Schoenoplectus tabernaemontani Temperate Herbaceous Vegetation
		Typha (angustifolia, latifolia) - (Schoenoplectus spp.) Semipermanently Flooded Herbaceous Alliance		
			CEGL002010	Typha (latifolia, angustifolia) Western Herbaceous Vegetation
		Undescribed Alliance		
			Park Special 3	Carex athrostachya Herbaceous Vegetation
	Forb herbaceous wetland			
		Argentina anserina Herbaceous Alliance [Provisional]		
			CEGL005825	Argentina anserina Herbaceous Vegetation [Provisional]
		Equisetum fluviatile Semipermanently Flooded Herbaceous Alliance		
			CEGL002746	Equisetum fluviatile Herbaceous Vegetation
		Heracleum maximum Temporarily Flooded Herbaceous Alliance		
			CEGL005857	Heracleum maximum Herbaceous Vegetation
		Senecio triangularis Temporarily Flooded Herbaceous Alliance		
			CEGL001987	Senecio triangularis Herbaceous Vegetation
		Trollius laxus Saturated Herbaceous Alliance		
			CEGL005858	Trollius laxus - Parnassia fimbriata Herbaceous Vegetation
	Hydromorphic-rooted vegetation			
		Myriophyllum sibiricum Permanently Flooded Herbaceous Alliance		
			CEGL002000	Myriophyllum sibiricum Herbaceous Vegetation
		Nymphaea odorata - Nuphar spp. Permanently Flooded Temperate Herbaceous Alliance		
			CEGL002001	Nuphar lutea ssp. polysepala Herbaceous Vegetation

Class	Subclass	Alliance	CEGL Code	Association Name
		Stuckenia pectinata Permanently Flooded Herbaceous Alliance		
			CEGL002003	Stuckenia pectinata - Myriophyllum (sibiricum, spicatum) Herbaceous Vegetation
Sparse Vegetation				
		Aquilegia (caerulea, flavescens) Sparsely Vegetated Alliance		
			CEGL005899	Aquilegia flavescens - Senecio megacephalus Sparse Vegetation
		Athyrium americanum Sparsely Vegetated Alliance		
			CEGL005900	Athyrium americanum - Cryptogramma acrostichoides Sparse Vegetation
		Phacelia hastata Sparsely Vegetated Alliance		
			CEGL005901	Phacelia hastata - (Penstemon ellipticus) Sparse Vegetation
			Park Special 1	Penstemon ellipticus Dwarf-shrubland
		Saxifraga bronchialis Sparsely Vegetated Alliance		
			CEGL005902	Saxifraga bronchialis Scree Slope Sparse Vegetation
		Saxifraga (chrysantha, mertensiana) Sparsely Vegetated Alliance		
			CEGL005903	Saxifraga mertensiana Cliff Crevice Sparse Vegetation
		Undescribed Alliance		
			Park Special 5	Undefined Sparse Vegetation

Appendix G: Descriptions to Plant Associations of Waterton-Glacier IPP provides vegetation descriptions of all the NVC plant associations recognized with this project and is organized according to the NVC physiognomic hierarchy (FGDC 1997). For most associations, diagnostic and abundant species, cover by strata and species, and other "concepts" are provided along with narrative local descriptions. When associations are known to occur outside the project area, a global description is provided, along with the literature sources used for that description. New and updated associations were incorporated into NatureServe's databases.

Plant Association Field Keys

We also developed dichotomous field keys to the plant associations of Waterton-Glacier IPP (Appendix H: Field Keys to Plant Associations of Waterton-Glacier IPP). The keys are designed to assist users in identifying vegetation associations in the field. The field key has two levels. The first level defines the physiognomy of the vegetation (forest, woodland, tall shrubland, shrubland, dwarf-shrubland, graminoid, or forb). The second level focuses on dominant species canopy cover and indicator species for the association. Understandably, the key functions on correct identification and proper estimation of characteristic plant species (see Use of the Vegetation Key in Appendix H for specific instructions and definitions).

Field keys were initially constructed from vegetation sampling plot data used to complete the classification analyses and was subsequently revised following the acquisition of AA observation plot data. Because the keys are based on a sample of the vegetation at Waterton-Glacier IPP, it is reasonable to conclude that not all associations of Waterton-Glacier IPP are captured, nor the full range of variation within a plant association.

MicroSoft Access Database

The field data collected from the vegetation sampling plots and AA observation plots were entered into the PLOTS Database System, and reside in a Microsoft Access database. In addition to the standard tables derived from the vegetation sampling plots and AA observation plots, several other tables were included to enhance the usefulness of the database. We included several "metadata" forms in the database to describe the contents of this database. We summarize the "metadata" forms below:

- Tables containing the vegetation sampling plot data from GNP, WLNP, Grasslands Ecology Project of GNP, and the Ecological Land Classification of WLNP;
- Tables containing the AA observation plot data from GNP and WLNP;
- Tables containing our comments on the AA observation plot data (reviews of the AA data were conducted);
- A table of the final vegetation classification; each association contains a listing of all vegetation plots, AA observation plots, common names, global conservation status rank, and state distributions associated with it;
- A table presenting each association in the 1997 version of the NVC physiognomic hierarchy,
- Tables listing the file names of ground photos taken for each vegetation sampling plot and AA observation site, along with the final NVC name assignment;
- A table documenting the original taxonomic names encountered in the vegetation sampling plot and AA observation plot data, and how we revised those names to match the NRCS PLANTS Database (USDA NRCS 2004); and
- A table with the final species list of Waterton-Glacier IPP and environs as documented from the vegetation sampling plot and AA observation plot data, and standardized to the NRCS PLANTS Database.

Discussion

Classification Concepts

Although the vegetation classification we developed for the Waterton-Glacier IPP Vegetation Mapping Project followed the general precepts of the NVC (FGDC 1997, Grossman et al. 1998), there were certain existing constraints guiding our results. We discuss a brief synopsis of "philosophy" and history regarding vegetation classification in northwestern United States and Canada since it is pertinent to the approach we took with this project.

The northwestern United States and western Canada had plant association (or community type) level classifications in place (Daubenmire 1952; Krajina 1960, 1965; Hall 1973; Pfister et al. 1977) long before other regions of either country had begun any extensive effort to develop a classification. Most of these classifications were practically oriented, intended to stratify landscapes by a component's ability to produce resources and were based on potential natural vegetation. The plant associations of these studies, based upon sampling late seral to "climax" vegetation, are termed "climax" to reflect their potential vegetation nature.

Many of the environments encompassed within Waterton-Glacier IPP have been classified at the climax association level (Pfister et al. 1977; Mueggler and Stewart 1980; Hansen et al. 1995) using an indicator species concept to recognize classification units (associations and phases). The plant associations recognized by these foregoing investigations have been incorporated into the NVC. However, other classifications within the WLNP portion of the study area base themselves on existing dominance by layer (Achuff et al. 2002a) and have not been incorporated into the NVC.

The present national approach to vegetation classification (employed herein) attempts to classify all vegetation to the association level, regardless of successional stage. Thus, when a forest stand contains trace amounts of a potential climax overstory species, such as sapling *Abies lasiocarpa* in a stand of mature *Pinus contorta*, the stand would receive the nominal *Abies lasiocarpa* / __ instead of the typical NVC approach of *Pinus contorta* /__ for the dominant canopy. Thus, this project was faced with trying to capture the wealth of information and ecological insight incorporated in existing "climax" and "dominance by layer" classifications while simultaneously trying to recognize seral stages of various vegetation types. In particular, this was the case for forest and woodland vegetation types.

A number of new NVC plant associations were identified for the Waterton-Glacier IPP by applying the above approach to previously identified habitat types. "Phases" of habitat types—also known as successional stands—were recognized as full associations if vegetation sampling plot data were available to substantiate them, and the type had been documented in existing habitat typing literature for the northern Rockies of the United States (e.g., Pfister et al. 1977; Mueggler and Stewart 1980; Steele et al. 1981, 1983; Cooper et al. 1987).

Vegetation Patterns and Ecology

We can gain considerable insight into vegetation ecology at Waterton-Glacier IPP merely by examining the distribution of tree species and several allied species. The mountainous spine following the CD, mostly of a north-south direction, roughly bisects GNP and also forms the western boundary of WLNP. This mountain range significantly influences the contrasting climatic regimes east and west of the CD, and ultimately the resulting vegetation types and their distribution. The mountainous terrain along the CD—although of lower elevation relative to the Canadian or Colorado Rockies—functions as both an effective barrier to Arctic air masses, which move southward across the Northwestern Great Plains and bank up against these ridges, and as an orographic stimulant to moisture laden Pacific air.

By all indications, the terrain west of the CD in GNP receives considerably less precipitation than coastal regions further west. However, sufficient amounts of precipitation still occur (certainly within swales or other collecting positions) to support species associated with the temperate Pacific Northwest (Figure 28), such as western red-cedar (*Thuja plicata*), western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), western white pine (*Pinus monticola*), Pacific yew (*Taxus brevifolia*), lady fern (*Athyrium filix-femina*), oak fern (*Gymnocarpium dryopteris*), and sword fern (*Polystichum munitum*). These species, however, are not found (with a few minor exceptions) east of the CD. Even though the above-cited species occur in Waterton-Glacier IPP, it is obvious some of these species are at their far eastern range. For example, Pacific yew occurs in GNP only as a stunted shrub <2 m in height, whereas a mere couple hundred miles westward, this yew can grow as a short tree, up to 15 m tall. Another example, lady fern occurs in riparian or subirrigated environments of GNP, yet seldom exceeds 7–9 dm in height, not reaching the 1.2–1.6 m attained by specimens in northern Idaho. Although present, grand fir is somewhat rare when compared to western red-cedar or western hemlock, which may attest to a population of limited genetic diversity.

Figure 28. Cedar-hemlock forest above Avalanche Lake, Glacier National Park.

The above-noted exceptions to general distribution patterns can pose challenging ecological conundrums. One case in point is found east of the CD at the head of Waterton Lake. Here, an extensive old-growth Engelmann spruce (*Picea engelmannii*) forest occurs on a presumably subirrigated bench. The forest has rich undergrowth, with the dominant oak fern a robust 2–3 dm in height. Without glancing upward for clues, one certainly would think they were in a mesic cedar-hemlock forest west of the CD.

Western larch (*Larix occidentalis*) and ponderosa pine (*Pinus ponderosa*), neither one moisture dependent as with any of the above-cited species, rarely occur and never occur, respectively, east of the CD. Western larch, despite being a common dominant of seral forests west of the CD, is restricted to west of the CD as a forest community and is rarely associated with other forest communities (e.g., spruce-fir) east of the

CD. The scarcity of ponderosa pine is due in large part to the forests of Waterton-Glacier IPP being predominantly subalpine, fundamentally beyond this species' cold tolerance. In the warmer montane conditions west of the CD where ponderosa pine can grow, it has a competitive disadvantage when cedar-hemlock is dominant.

The Lake McDonald drainage within GNP has species with a close affinity to the Pacific Northwest, and is also the eastern most distribution for nearly all of the species cited above. The ultra-mesic to wet and the comparatively warm environments of this drainage (comparatively, that is, to Waterton-Glacier IPP) support old-growth cedar-hemlock forests towering >35 m in height. A smattering of the highly fire-resistant western larch—some of the oldest trees in the park—are often found emerging an additional 10–12 m above the main forest canopy of these old-growth forests (Figure 29). If a stand-replacing fire coincides with an abundant cone crop, nearly pure stands of western larch can establish.

Figure 29. Emergent western larch reaching above a cedar-hemlock forest canopy.

Species with an affinity to the Pacific Northwest are also found southward of the Lake McDonald drainage along the Middle Fork Flathead River. The south-facing slopes, prior to the extensive fires of 1910, most likely supported abundant western red-cedar, and have since been unable to re-colonize due to the severity of the burn, possibly due to subsequent erosion events associated with the steep slopes. Today, only scattered remnants of cedar-hemlock trees remain in these areas.

Of the Waterton-Glacier IPP tree flora, only one species, limber pine (*P. flexilis*), is found exclusively east of the CD. It is almost always associated with well-drained, calcareous substrates and warm exposures, and often on steep slopes and wind-buffeted positions. A testable explanation for this distribution has not been advanced. (One can hypothesize, however, the wingless-seeds are simply not a sufficient vector to disperse seed long-distances across inhospitable habitat to the west.) This short-statured tree—usually <12 m at maturity—comprises woodlands found on foothills and low-elevation calcareous ridges of the Blackfeet Indian Reservation, and extends to higher elevations of Waterton-Glacier IPP where its distribution overlaps with the lower elevation occurrences of another five-needle pine, whitebark pine (*P. albicaulis*). Both species are "stone pines," having wingless seeds, and are a rich source of nutrients to wildlife, particularly bears prior to hibernation, squirrels, and Clark's nutcrackers at their return of spring migration. (The Clark's nutcrackers harvest seeds from cones, whereas bears raid squirrel caches.) Whitebark pine, primarily a post-fire seral species and having a symbiotic relationship of mutualism with the Clark's nutcracker, is found throughout the upper elevations of the subalpine zone, and are not uncommon as large, even-aged stands with southerly or westerly exposures. These large stands of a wingless seeded pine give testimony to the caching abilities of the Clark's nutcrackers. Clearly the nutcrackers do not recover all their caches since they strongly favor caching on slopes that will be snow-free upon their return from migration, and cold exposures are within the environmental range of whitebark pine.

Limber, whitebark, and western white pine (*P. monticola*), as with all five-needle pines, are hosts of white pine blister rust (*Cronartium rubicola*), which infests and eventually kills these species. Whereas federal managers have been concerned with blister-rust as a cause of western white pine mortality for more than half a century (including those of the park), little attention was devoted to the two stone pines. Within the last decade, however, the ecological importance and precarious status of populations of both species have been better understood—whitebark pine to the extent that it is said to be "ecologically extinct" within GNP—with dead stands visible for miles from the characteristic reflectance of their barkless boles and branches (Figure 30). Apparently, both stone pines have a low resistance (perhaps one tree in 10,000) to this introduced rust. A "needle-in-the-haystack" search has begun for specimens resistant to the rust, with hopes of cultivating the resistant specimens within the park. Consequences resulting from the loss of this food source, particularly to grizzly bear populations and as it cascades through the food chain, remain a matter of great concern to managers.

Figure 30. Whitebark pine mortality due to the white pine blister rust.

By far, the most extensive life zone is the subalpine, characterized by the presence of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce. Often these two relatively long-lived, highly shade-tolerant species are dominant in the subcanopy, growing slowly to be released with the death of the short-lived lodgepole pine (*P. contorta*). In other scenarios, subalpine fir and Engelmann spruce live and reproduce beneath the canopy of longer-lived western larch or Douglas-fir (*Pseudotsuga menziesii*), often not attaining full canopy dominance before a fire event initiates the next successional cycle. Lodgepole pine, the shortest-lived coniferous tree (80–130 [150] years), is probably the most abundant tree species at Waterton-Glacier IPP. It has the greatest ecological amplitude of any tree species in the park and is an efficient post-fire colonizer. It attains sexual maturity at an early age and virtually always has a viable seed crop (due to the serotinous nature of the long-retained cones). Lodgepole pine occurs from the montane to all but the highest elevations of the subalpine zone and from excessively drained calcareous soils, where limber pine dominates with bearberry and bunchgrass, to Carrs, where the undergrowth is composed of bog birch (*Betula nana*), wet-site sedges, and even sphagnum mosses on perennially saturated soils or in standing-water. The relative abundance of lodgepole pine is greatest in the upper subalpine where few other competing seral tree species exist.

Krummholz exist at the highest elevations or on the most exposed positions of the subalpine zone. It is characterized with a stand structure of dwarfed and flagged shrub-sized trees, often growing in a dense, mat-like, and virtually impenetrable thicket (Figure 31). Trees composing krummholz include subalpine fir, Engelmann spruce, whitebark pine, and Douglas-fir. (Douglas-fir is far less common than other trees.)

Figure 31. Krummholz shrubland of the high-subalpine zone.

Also, at the highest elevations and most exposed sites of the subalpine, is subalpine larch (*Larix layalli*). Distribution of subalpine larch is quite erratic within Waterton-Glacier IPP. Its stands are often distanced from each other and remain absent from upper subalpine environments with rocky substrates and positions with late-persisting snow cover. The undergrowth of subalpine larch stands are often dominated by smooth rush (*Luzula glabrata* v. *hitchcockii*) or ericaceous dwarf-shrubs, whose presence gives evidence to deep and late-persisting snowpacks of these sites. It is worth noting of subalpine zone, only one coniferous tree species is native to Montana—mountain hemlock (*T. mertensiana*)—and has not been recorded for Waterton-Glacier IPP, which reflects the park's diversity of habitat and flora.

By definition, the alpine zone is tree-free, although it is debatable whether stands of krummholz, which are an extensive landscape component at Waterton-Glacier IPP, are more alpine or subalpine in their ecological affinities. The climate of the alpine zone is obviously inimical to the establishment and growth of tree species. Many have hypothesized as to what the driving factors are and what their interactions are that discourage tree establishment. It is generally conceded that in the alpine zone temperatures are suboptimal for photosynthesis, the frozen and physiologically cold soils allow only a narrow window for plants to take root, and desiccating winds with entrained abrasive particles are challenging to life forms with exposed perennating buds.

At the lowest elevations with relatively warm microclimates, the subalpine zone supports a highly diverse assemblage of undergrowth species, both shrubs and herbs. In wet environments supporting both subalpine fir and spruce, devil's club (*Oplopanax horridus*) occurs with a rich component of ferns and mosses. Also, at sites judged even wetter (more oxygen deprived), horsetail (*Equisetum arvense*) or willows (e.g., Drummond's willow, *Salix drummondiana*) are characteristic with only spruce present in the canopy (subalpine fir or lodgepole pine may rarely be present).

East of the CD, at the lower fringes of the subalpine zone and into the montane, small and more monotypic stands of spruce exist, often mixed with trembling aspen (*Populus tremuloides*) or black cottonwood (*P. balsamifera* ssp. *trichocarpa*). Examination of cones sampled from local populations indicate (based on cone characteristics alone) hybridization is occurring between Engelmann spruce and white spruce (*P. glauca*). Some spruce trees, on the basis of gross morphology (not just cone features), could not be distinguished from "pure" white spruce. These hybrid spruce populations indicate that some degree of a boreal regime is manifested along the Rocky Mountain Front.

Throughout Waterton-Glacier IPP, with the conspicuous exceptions of the mesic cedar-hemlock forests of the Lake McDonald drainage and those extending north and south of West Glacier, the so-called montane zone exists as a discontinuous presence on the most xeric forested sites supporting Douglas-fir or limber pine as potential climax species. With these sites being sufficiently xeric (due to exposure, moderate to steep southerly exposures, or excessively drained soils), the only tree species not capable of occurring in the montane zone are subalpine larch (*L. layalli*) and whitebark pine (*P. albicaulis*). Ponderosa pine is restricted to montane environments and lowest elevation subalpine forests west of the CD where it is warmer. The modal undergrowth condition within dry-montane is characterized by the dominance of short- to mid-sized shrubs such as white spirea (*Spiraea betulifolia*), common snowberry (*Symphoricarpos albus*), common juniper (*Juniperus communis*), Oregon grape (*Mahonia re*pens), and the virtually ubiquitous pine grass (*Calamagrostis rubescens*). The most xeric habitats supporting trees in the montane are open woodlands characterized by any of the above named trees with an undergrowth characterized by bunchgrasses, such as Idaho fescue (*Festuca idahoensis*), rough fescue (*F. campestris*), bluebunch wheatgrass (*Pseudoroegneria spicata*), and dwarf shrubs (e.g., kinnikinnick, *Arctostaphylos uva-ursi*).

Three deciduous tree species are found in Waterton-Glacier IPP: trembling aspen (*P. tremuloides*), black cottonwood (*P. balsamifera* ssp. *trichocarpa*), and paper birch (*Betula papyrifera*). They function as seral species, occasionally forming monotypic stands and eventually giving way to conifer dominance (although this may not take place on the most dense aspen stands occurring on deep loessel soils). Paper birch is a short-lived species occurring only west of the CD, ranging from montane to subalpine habitats. It often characterizes stands with some of the greatest species diversity and often is oddly associated with high coverages of wild sarsaparilla (*Aralia nudicaulis*). Both poplar species are short-lived—no specimen in the Waterton-Glacier IPP exceeded 130 years—and are associated with herb-rich undergrowths in mesic conditions; the herbs are a favored spring food of foraging grizzly bears. Conventionally, black cottonwood is thought to favor wetter sites, but the two poplar species co-occur on many sites, although trembling aspen definitely extends to drier environments where pine grass, elk sedge (*Carex geyeri*), and common snowberry are dominant undergrowths. One of the most intriguing black cottonwood distributions is on old burns along Going-to-the-Sun Road, where it occurs at higher elevations of subirrigated landscapes, and in juxtaposition to vast shrub fields (Figure 32). (The typical landscape positions of black cottonwood are lower elevation riparian stringers or ultra-mesic to wet swales.)

Figure 32. Black cottonwood in the subalpine zone along Going-to-the-Sun Road, Glacier National Park.

A striking phenomenon is in comparing tree heights of *Populus balsamifera* ssp. *trichocarpa* (black cottonwood) west of the CD with those east of the CD. Black cottonwood top out at 15–16 m east of the CD, whereas those west of the CD have been measured in excess of 40 m (in riparian settings).

Trembling aspen rarely exceed 15 m when east of the CD; whereas the tallest aspen west of the CD measured 26 m in height. These differences in tree height exist despite being the same plant associations found in similar abiotic conditions on either side of the CD. We speculate the differential factor is primarily due to drying winds, specifically downslope (Chinooks), of which the region east of the CD is known for (The Rocky Mountain Front between Lethbridge, Alberta and Dupuyer, Montana, has more Chinook days than any other part of North America). One can observe the wind effect on a local scale throughout the Blackfeet Reservation where the trembling aspen show a decline in height from the crest of a knob or hill to the lee slope base. Trees at the crest are one half to one third the height of the trees at the base—short slopes augmenting water supply is unlikely a contributing factor. One simply can envision this phenomena on a much larger scale to appreciate how Chinooks, which essentially are a manifestation of prevailing winds and topography, literally shape the vegetation diversity east of the CD with respect to west of the CD.

Although Waterton-Glacier IPP is largely of forested terrain, it is abundantly clear from the list of plant associations that vegetation types at this park are diverse. We anticipated this, being Waterton-Glacier IPP is large and sits amongst a major east-west ecotone with several converging regional floras. Using the portion of the landscape supporting trees (forests and woodlands); the above exposition has been an attempt to present some explanation of the biotic diversity at Waterton-Glacier IPP in simple terms of ecology.

Disturbances

By far, the most important disturbance in this landscape is fire (Figure 33). Fire manifests itself in various intensities, from a stand-replacing crown fire having expectant post-fire successional stages, to a creeping ground fire that opens the door to unique post-fire successional growth patterns. For example, stand-replacing fires followed by repeated ground fires may explain the area north of Polebridge where stands of mountain sagebrush (*Artemisia tridentata* ssp. *vaseyana*) are well within a subalpine environment and have the potential to support tree species. Even during this project, near 45,000 ha were burned to some degree (mostly stand-replacing), reinforcing the magnitude of fire as a disturbance factor. Perhaps this lends credence to the hypothesis that existing forests—even within Waterton-Glacier IPP—are out of the historic range of variation with regard to stand-replacing fire.

Figure 33. A field of *Epilobium angustifolium* (fireweed) in response to recent fire at Glacier National Park.

Although they affect less area than fire, snow avalanches are the most prevalent disturbance phenomenon, generally confined to higher elevations and steep slopes (>45%) within the subalpine zone. In appropriate terrain, slides can gather sufficient momentum to run thousands of vertical feet and terminate in the montane zone, even crossing narrow valley bottoms and ascending short distances up opposing slopes. Generally, an avalanche occurs with some degree of regularity at the same location (Figure 34). As a result, prevailing shrub-fields (or less commonly forb-fields) are generated. Avalanche sites are typically mesic to sub-hydric, and support a dense canopy of shrubs, including alder species (*Alnus* spp.), rusty menziesia (*Menziesia ferruginea*), mountain ash species (*Sorbus* spp.), and globe huckleberry (*Vaccinium membranaceum*). In some instances, a given area may not be particularly slide-prone. These areas may not experience a slide for many years, or have regular low-magnitude slides, and then a large-magnitude slide will occur in time. Evidence for this scenario are areas with scattered, ragged old dead boles having been snapped-off 3–5 m high (the tops are entrained in the flow and can be found in debris piles at the terminus) and having well dispersed young trees (seedling to small pole-sized) projecting through the shrub field.

Figure 34. Shrub and forb fields within avalanche chutes on a steep mountain slope.

Vegetation Mapping

Methods

Mapping vegetation of Waterton-Glacier International Peace Park (IPP) and environs involved four primary steps; (1) field reconnaissance, (2) map classification, (3) photointerpretation, and (4) digital map automation and database development. Although these steps occurred sequentially, they overlap to some degree.

The entire mapping process of the Glacier National Park (GNP) spatial database was accomplished by the U.S. Geological Survey (USGS) Upper Midwest Environmental Sciences Center (UMESC) mapping team. For the Waterton Lakes National Park (WLNP) spatial database, the mapping process was performed by various groups and individuals. Table 13 shows the primary groups or individuals directly responsible in carrying out various stages of the mapping processes.

Table 13. Various groups or individuals and their contribution to the vegetation mapping of Waterton-Glacier International Peace Park.

Map Process	GNP and Environs	WLNP and Blood Timber Limit
Field Reconnaissance	USGS UMESC	WLNP Contractor
Map Classification	USGS UMESC and WLNP Contractor	USGS UMESC and WLNP Contractor
Photointerpretation	USGS UMESC	WLNP Contractor
Digital Map Automation and Database Development	(see below)	(see below)
Geo-reference (OrthoMapper)	USGS UMESC	WLNP Staff
Digitize Polygons and Attributes	USGS UMESC	WLNP Contractor
Database Development	USGS UMESC	USGS UMESC*

*The U.S. Geological Survey Upper Midwest Environmental Sciences Center developed the Waterton Lakes National Park map database to promote synchronized polygon and attribute data between the Glacier National Park and Waterton Lakes National Park spatial databases.

Field Reconnaissance

In preparation to map vegetation types, photointerpreters invested several days in the field investigating ground conditions with aerial photographs in hand. This process is necessary, as Hershey and Befort (1995) explain, because photography is not consistent between photo sets to allow a species or type to be described precisely. Film batch, printing process, sun angle, light intensity, shadow, and exposure can all affect the appearance.

We engaged in formal ground verification of the aerial photos to correlate vegetative photo signatures—appearances of vegetation on the aerial photographs—to vegetation on the ground (Figure 35). Here is where photointerpreters began to discover limitations of interpreting plant communities using aerial photographs. Where limitations were discovered, environmental models were tested in the field (e.g., slope, aspect, and elevation) to determine if plant communities could be consistently separated by environmental elements. Field reconnaissance also allowed photointerpreters to become more familiar with the local ecology of plant communities, which is always important when applying ecological concepts to the photointerpretation mapping.

Much of this ground truthing effort was accomplished as a team combined of mappers and ecologists, to ensure photointerpreters assessed the vegetation types in the field correctly in order to apply them correctly during photointerpretation mapping. Since vegetation mapping was to proceed simultaneously with vegetation classification development (vegetation sampling plots, analyses, and descriptions), this posed problems for developing map classes and map conventions for photointerpretation application, and even more so, the necessity of mappers working jointly in the field with ecologists. Most of the mapping team's ability to recognize vegetation types on the ground depended on field discussions with the vegetation classification team.

Figure 35. Ground truthing aerial photographs at Waterton-Glacier International Peace Park.

As ecology and mapping teams, we discussed the structural, floristic, and habitat characteristics of the vegetation encountered in the field and compared them to their appearance on the photos. Through this process, we built an understanding of how to map the vegetation types (or anticipated types). We also established a working map classification with mapping protocols, and continually adjusted and updated the protocols as new information from mapping fieldwork and vegetation sampling analyses (for vegetation classification) became known.

The photo contact prints were taken into the field, with notes recorded onto photo jackets. These field notes included map class assignment, if known, as well as significant species to promote proper perspective of species composition for photointerpretation (e.g., heterogeneous vs. monotypic stand of conifers). Also noted was any information that might help the photointerpretation mapping with linking photo signature to an appropriate map class. Estimated tree heights were occasionally recorded to give a perspective when applying the physiognomic height modifier during the mapping, a serious challenge given the changing photo scale inherent to aerial photos of mountainous terrain. In essence, we would build a "model" of photo signatures to base our decisions on during photointerpretation mapping. This process is repeated until photo signatures become familiar.

Map Classification

Our ultimate goal with a map classification was to represent the plant communities of Waterton-Glacier IPP as defined with this project. The goal of the USGS-National Park Service (NPS) Vegetation Mapping Program (VMP) is to map the finest level of the National Vegetation Classification (NVC), which is the association (plant community). The relation of a map class to a plant community can be complex. What we see on the aerial photographs is not necessarily what defines the plant community. Often, for instance, we are unable to map plant communities independently of each other because floristic components on the aerial photographs cannot be discerned. Consequently, we map those communities together as one map class.

Map classes representing vegetation types of Waterton-Glacier IPP are based on a working knowledge of aerial photograph signatures to our understanding of vegetation types at the time of mapping. Where aerial photos limit our ability to differentiate between plant associations, we strived to strategically bundle vegetation types together under one map class. Deriving a map classification prior to having the vegetation classification complete was problematic. Not knowing what plant communities truly exist, nor knowing their variable expressions within, made it difficult to group vegetation types together and derive conventional mapping rules for consistent mapping. Thus, ongoing discussions between mappers and ecologists continued throughout the entire project to promote a clearer understanding of the relationships between map classes and vegetation types; minor revisions were made toward the end of the project.

Map classes developed slowly. Each field endeavor revealed new information, promoting us to modify map classes and their definitions. We continually made revisions as the vegetation classification developed. Furthermore, as more and more aerial photos were interpreted, new issues arose, which forced us to redefine, expand, or polish each map class definition. Finally, the accuracy assessment (AA) observation plot data provided a plethora of information, refining concepts of the vegetation classification, thus refining the concepts of the map classes representing them. Throughout the entire process, we adjusted the map classification as needed to best reflect the vegetation classification we knew at the time.

Map classification and protocols are based on existing classification systems. We linked map classes representing natural/semi-natural plant communities to NVC associations as identified by NatureServe. Some vegetation types could not be assigned to a plant community because of disturbance (e.g., shrub-herbaceous regeneration from recent fire). For those map classes, we assigned the appropriate NVC Alliance type (or more rarely, the Formation type). For non-vegetated features (e.g., roads, urban areas, non-vegetated bodies of water), we derived map classes corresponding closely with Anderson et al. (1976) land cover and land use classification.

We derived a map code for each map class merely for ease of assigning information to map polygons and as a short-hand language amongst team members. For each polygon, a map attribute code is assigned, which is a code constructed of two sections: (1) a single map class code and (2) a set of physiognomic modifier codes. A hyphen separates the two code systems (e.g., [map class code]-[set of physiognomic modifier codes]).

A map class code is made up of three alpha characters and represents an independent map class. Each vegetation map class code begins with the first alpha representing the NVC Class, as follows:

- “F” for Forest,
- “W” for Woodland,
- “S” for Shrubland,
- “D” for Dwarf-shrubland,
- “H” for Herbaceous Vegetation,
- “V” for Sparse Vegetation,
- “C” for Complex (complex map classes of Dwarf-shrubland and Herbaceous Vegetation), and
- “X” for Agricultural Vegetation (technically under the Herbaceous Vegetation Class).

For non-vegetated features, map class codes begin with “N” for Non-vegetated.

The subsequent two alpha characters for each map class loosely represent the map class description (e.g., LP for lodgepole pine, WM for wet meadow, RR for road/railroad).

The physiognomic modifier codes are strings of alpha and numeric characters and, when applicable, follow the map class codes. These physiognomic modifiers provide additional information describing the physiognomic characteristics of the vegetation within each mapped polygon. The coverage density, coverage pattern, and height physiognomic modifiers are standard to VMP projects. The whitebark and limber pine habitat component modifier, which we applied to map classes falling within specific geo-ecological locations, is project specific to Waterton-Glacier IPP, and supports resource management in identifying areas that potentially contain whitebark and limber pines that are resistant to the white pine blister rust. Table 14 lists the physiognomic modifiers we used for mapping Waterton-Glacier IPP.

Table 14. Physiognomic modifiers assigned to polygons during photointerpretation.

Category	Modifier	Meaning
Coverage density (Applied to all vegetation map classes)	1	Closed Canopy/Continuous (60-100% cover)
	2	Open Canopy/Discontinuous (25-60% cover)
	3	Dispersed-Sparse Canopy (10-25% cover)
Coverage pattern (Applied to all vegetation map classes)	A	Evenly Dispersed
	B	Clumped/Bunched
	C	Gradational/Transitional
	D	Regularly Alternating
Height (Applied to woody terrestrial vegetation map classes only; Forest, Woodland, Shrubland, and Dwarf-shrubland)	1	30-50 m (98-162 ft)
	2	15-30 m (50-98 ft)
	3	5-15 m (16-50 ft)
	4	0.5-5 m (1.5-16 ft)
	5	<2 m (<1.5 ft) (park specific; SFK map class only)
	6	<0.5 m (<1.5ft) (Dwarf-shrubland map classes only)
Whitebark and Limber Pine Habitat Component Modifier (park specific; all map classes except those used in valley bottoms and wetlands)	X	Dead (significant dead trees of any species present within the polygon; no live whitebark and/or limber pine trees)
	Y	Dead and Alive (significant dead trees of any species and live whitebark and/or limber pine trees present within the polygon)
	Z	Alive (all whitebark and/or limber pine trees present within the polygon appear alive within the polygon)

An example of a map attribute code is “WFS-2A3Y.” This map attribute code describes those map polygons with vegetation types assigned to the Subalpine Fir - Engelmann Spruce Woodland (WFS) map class, with a coverage density of 25–60%, a coverage pattern that is evenly distributed, an average tree height of 5–15 m (16–50 ft) and having live whitebark and/or limber pine along with a significant presence of dead trees (any species).

Having this series of map classification and physiognomic modifiers can greatly enhance the interpretation of the map coverage for managers and researchers, particularly when introducing other geospatial data sets. For instance, if a bird researcher was seeking potential survey sites near Saint Mary Lake having small grasslands (e.g., 0.10–0.25 ha, which is smaller than the minimum mapping unit, [MMU]) surrounded by short-statured, colonizing aspen, the researcher could employ a geographic information system (GIS) and select all FAP-2B4 (aka: Aspen Forest having 25–60% canopy cover, clumped coverage pattern, and 0.5–5 m average tree height) in the Saint Mary Lake area occurring in elevations below 5,000 m. Prospective sites could then be visited to determine suitability as a survey site.

Photointerpretation Mapping

Glacier National Park Photointerpretation Mapping

Choice of Aerial Photographs for Mapping: We chose the August 1999 true color (TC) aerial photos (1:15,840-scale) as our primary mapping base rather than the August 1997 color infrared (CIR) aerial photos (1:24,000-scale) because the TC photos were of larger scale, the acquisition date was two years more current, and typically TC photos provide better perception through shadow than CIR photos. We continued to use, however, the August 1997 CIR photos to complement problematic photo signatures of the 1999 TC photos. Having in our possession two sets of aerial photographs collected from different dates and scales advanced our photointerpretation mapping.

As expected with aerial photography of the Rocky Mountain region, large shadows obscure the landscape (Figure 36). Although TC photography was a better choice than CIR photography for viewing through shadows, seeing through large and dark shadows still remained problematic. In some cases, where shadows are cast on the TC photos, they are shadow free (or more so free) on the CIR photos, merely because the photos were acquired at different times of day (difference in sun-angle). Also, adjacent flight lines often exhibited shadows of different sun-angles allowing some areas to appear shadow free. Although referencing all of these photos adds time to the photointerpretation process, we were able to attain at least visuals of the areas, thus make approximate delineations of vegetation types. Occasionally, we would also make an effort to check out other existing photo imagery. In some cases, however, shadows obscured an area on all ancillary imagery, in which mapping was extrapolated from surrounding visible areas to capture most likely vegetation.

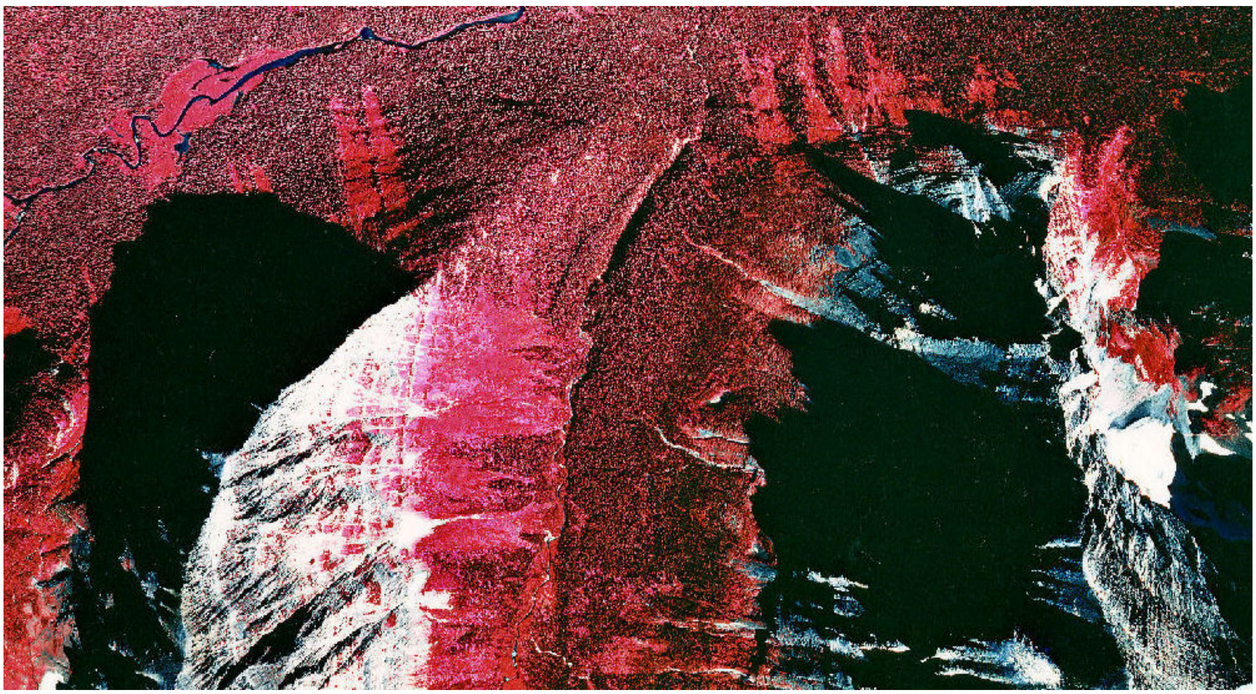

Figure 36. Shadows (the dark areas) obscuring the landscape on a color infrared aerial photograph.

Aerial Photointerpretation Mapping: Preparation of the aerial photographs for interpretation generally followed procedures of Owens and Hop (1995). We placed clear acetate overlays on each aerial photograph transparency used for mapping. Using the positive transparency photos for photointerpretation mapping provided us with the highest resolution possible. The transparency photos are also dimensionally stable (made of Estar base) and virtually not affected from temperature and humidity changes. The paper contact prints are less desirable because they are grainier and the paper base can expand and contract slightly with changes in temperature and humidity.

We registered each mapping overlay to the photos by the fiducials (standard reference points) and photo identification information. We viewed the photos for interpretation using Richards MIM light tables and Bausch & Lomb Zoom 240 stereoscopes with variable zoom capabilities (Figure 37). We used Topcon (MS-3) mirror stereoscopes with 3x binoculars to view the 1997 CIR aerial photographs (Figure 38).

Figure 37. Stereoscope equipment used for photointerpreting true color aerial photographs.

Figure 38. Stereoscope equipment used for photointerpreting color infrared aerial photographs.

Each transparency photo was paired up with the adjacent photo so we could view the images three-dimensionally. Normally we used the middle portion of each photograph for the photointerpretation data to minimize edge distortion. On occasion, we mapped near the photo edges to escape intense shadow casts or angle distortions inherent to images of extreme elevation change. We delineated feature polygons and scribed their corresponding map attribute codes onto the acetate overlays using Rapidograph ink pens (6x0-size, 0.13 mm) and Rapidraw black India ink (3084; waterproof, fast drying for film).

We typically drew larger polygons first and followed with smaller polygons down to the MMU guidelines. Inherent to these aerial photos—being of rugged mountainous terrain—are considerable angle distortions and significant scale changes from high ridges to low valley bottoms. Thus, in applying the MMU, we tended to err below the guideline rather than above. We applied standard photo signature characteristics, including texture, color, pattern, and position in the landscape to guide placement of polygons. In addition to photo signature characteristics, understanding the environmental distribution of the vegetation types helped us not only identify types, but also properly place polygon boundaries. For each polygon, we applied the appropriate map class code and physiognomic modifier codes (collectively, the map attribute code).

During our photointerpretation mapping, we employed other ancillary data sets to help in our mapping decisions. Of most prevalence, whitebark pine distribution data (Kendall and Keane 2001) provided us several locations to help us determine the vegetation composition of those areas; particularly with the presence of whitebark pine and limber pine, but of other tree species, too (e.g., subalpine larch). On occasion, we also used forest stand age data, which helped us understand historic fire occurrence and thus provided us insight into the seral stages of forests. We also reviewed the Waterton-Glacier IPP vegetation sampling plot data from this project, giving us straight-forward information consistent with our goals of mapping the plant communities.

When using these ancillary data sets, we took into consideration that the data from a particular plot were location-specific and not necessarily representative of the surrounding area as a whole—the plot sizes were generally quite small compared to the MMU size used for mapping. Although we used GIS to locate these sites, often times the surveyor notes helped us determine the plot's usefulness to our photointerpretation mapping.

All photointerpretation mapping of GNP and environs were performed via three individuals who were experienced in photointerpretation mapping of vegetation. Once complete, we subjected our photointerpretive data to rigorous quality control, with each interpreted overlay being reviewed by another experienced photointerpreter who was well rehearsed in mapping vegetation of Waterton-Glacier IPP.

Waterton Lakes National Park

(Context of the following from Cheryl Bradley, written commun., February 2007)

Photointerpretation mapping of WLNP and environs (Blood Indian Timber Limit) were performed by the same individual who collected vegetation sampling plots of WLNP for the Waterton-Glacier IPP project. The photointerpreter collaborated with the UMESC mapping team regarding the mapping process and the map classification. Although phone calls and e-mail were the most economical modes of communicating, collaboration also included workshops and field meetings.

Photointerpretation methods were similar to those used in mapping GNP and environs. However, mapping equipment and ancillary data sets were different, and the mapping effort was performed separate and remote from the UMESC mapping team.

A Topcon (MS-3) mirror stereoscope placed over a light table was used to view the 1999 TC aerial photo prints three-dimensionally. Normal viewing was with a 3x binocular. However, a 6x binocular viewer was used to help determine tree crown distinctions, differentiate herbaceous and dwarf-shrub vegetation, and peer through shadows of mountains. Map polygons and map attribute codes were applied to the acetate overlays using a Rotring Rapidograph pen (4x0, 0.18 mm) and non-permanent ink.

Just as ancillary data sets were used to aid in the mapping of GNP, they were also used to aid in the mapping of WLNP. The Ecological Land Classification (ELC) maps (1:20,000-scale) of WLNP (Achuff et al. 2002b), which ecosite polygons were based from 1987 CIR aerial photos, provided landscape information in relation to landform, soils, and vegetation characteristic repetitions throughout the landscape. Also, ground surveys, as well as a forest cover map produced from late 1960 data (black and white aerial photos) were used to understand forest zones and successional stages. The whitebark pine distribution data (Kendall and Keane 2001), although only 14 plots in WLNP, was used to affirm whitebark pine and limber pine presence. Lastly, a report on the historic role of fire in WLNP (Barrett 1996), including 1:20,000-scale maps of forest stand age, was used to glean additional vegetation information.

Digital Map Automation and Database Development

Digital Map Automation

Glacier National Park

We converted the photointerpreted data into a GIS-usable format employing three fundamental processes; (1) orthorectify, (2) digitize, and (3) database enhancement. All digital map automation was projected in Universal Transverse Mercator (UTM) projection, Zone 12, using North American Datum of 1983 (NAD83).

Orthorectify: We orthorectified the interpreted overlays using OrthoMapper (Image Processing Software Inc., Madison, Wisconsin), a softcopy photogrammetric software for GIS. One function of OrthoMapper is to create orthorectified imagery from scanned and unrectified imagery (Image Processing Software, Inc., 2002). The software features a method of visual orientation involving a point-and-click operation using existing orthorectified horizontal and vertical base maps. This process was completed to produce orthophotographs of the park. Of primary importance to us, OrthoMapper also has the capability to orthorectify the photointerpreted overlays of each photograph based on the reference information provided from the orthophotographs.

First, we scanned each aerial photograph at 400 dots per inch (dpi) and 64 million colors, producing a series of Tagged Image File Format (TIFF) images. We then used OrthoMapper to register each image, establishing both horizontal and vertical coordinates. We used USGS 3.75-minute digital orthophoto quadrangle (DOQ) images to derive horizontal coordinates and USGS 7.5-minute digital elevation models (DEMs) to derive vertical coordinates of the aerial photo image. Once the orthophotos were created, we scanned each photointerpreted overlay and produced 2-bit (black-and-white) scans at a resolution of 600 dpi, again producing a series of TIFF images. Once more, we used OrthoMapper to register each overlay image, this time to their corresponding orthophoto. Finally, we mosaicked the orthorectified overlay images into workable groups (often around 20 overlays per group) for subsequent digitizing; we produced 78 groups of orthorectified overlay mosaics.

Digitize: To produce a polygon vector coverage for use in GIS, we converted each raster-based image mosaic of orthorectified overlays containing the photointerpreted data into a grid format using ArcInfo (Version 8.0.2, Environmental Systems Research Institute, Redlands, California). In ArcTools, we used the ArcScan utility to trace the polygon data and produce ArcInfo vector-based coverages. We digitally assigned map attribute codes (both map class codes and physiognomic modifier codes) to the polygons, and checked the digital data against the photointerpreted overlays for line and attribute consistency. Ultimately, we merged the 78 individual coverages into a seamless map coverage of GNP and immediate environs.

Waterton Lakes National Park

(Context of the following from Cyndi Smith, written commun., February 2007)

The GIS staff at WLNP orthorectified the photointerpreted overlays using OrthoMapper and orthorectified images of the 1999 TC aerial photos. The aerial photos were orthorectified and mosaicked by ATLIS Geomatics of Calgary, Alberta, Canada with additional projection information added by Miistakis Institute for the Rockies (associated with the University of Calgary) for proper display in OrthoMapper. Orthorectification was performed by Public Works and Government Services Canada.

(Context of Sandy Cummings, written commun., February 2007)

Digitizing was done using the orthorectified images of each photointerpreted overlay. Methods consisted of both automated means via ArcScan and manual means via ArcMap; about 90% of the work was accomplished manually. The orthorectified photo overlays were digitized individually. Once all overlays were digitized, they were edge-matched, and adjustments were made manually to obtain “best fits.” Additional minor adjustments were made to some edge-matches, using the 1999 TC aerial photo mosaic as a background image for visual referencing. Some digitized overlays needed shifting to compensate for spatial shift of the original orthorectified overlays. (This displacement was possibly due to the quality of the DEM used for referencing the individual aerial photos and their corresponding overlays.) The manual shifting was accomplished by visual means using the aerial photo mosaic imagery as the background reference.

The map coverage was projected in UTM, Zone 12, using NAD83, and transferred to the USGS UMESC for AA and final database development.

Waterton-Glacier IPP Map Coverage

We synchronized polygons and attributes along the boundary between the GNP and WLNP map coverages. Although GNP and WLNP are two separate map coverages, they are seamless in the sense they edge tie perfectly in both polygon location and map attribute.

Database Development

At this stage, the map coverages have only map attribute codes assigned to each polygon (Figure 39). To assign meaningful information to each polygon (e.g., map class names, physiognomic definitions, link to NVC association and alliance codes, Figure 40), we joined an attribute table linking additional information to the map coverages.

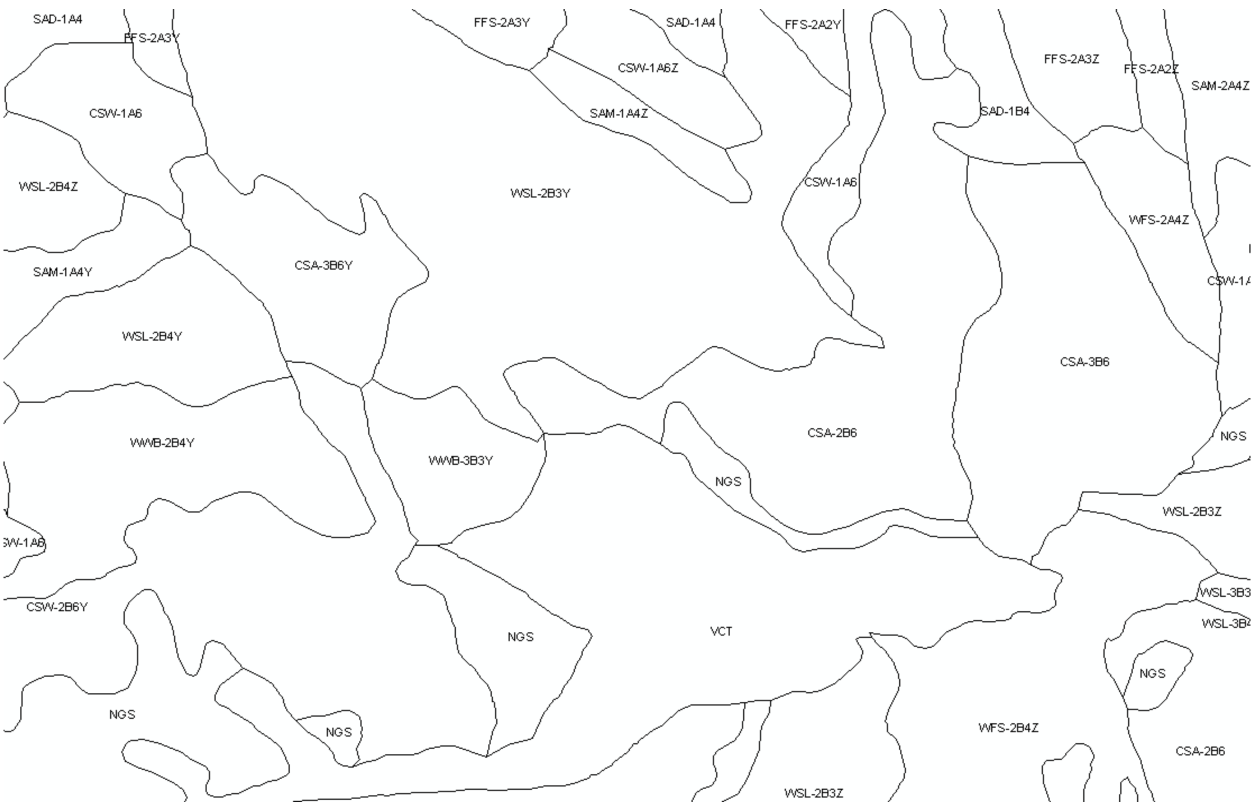

Figure 39. Map polygon with only map attribute code assignment.

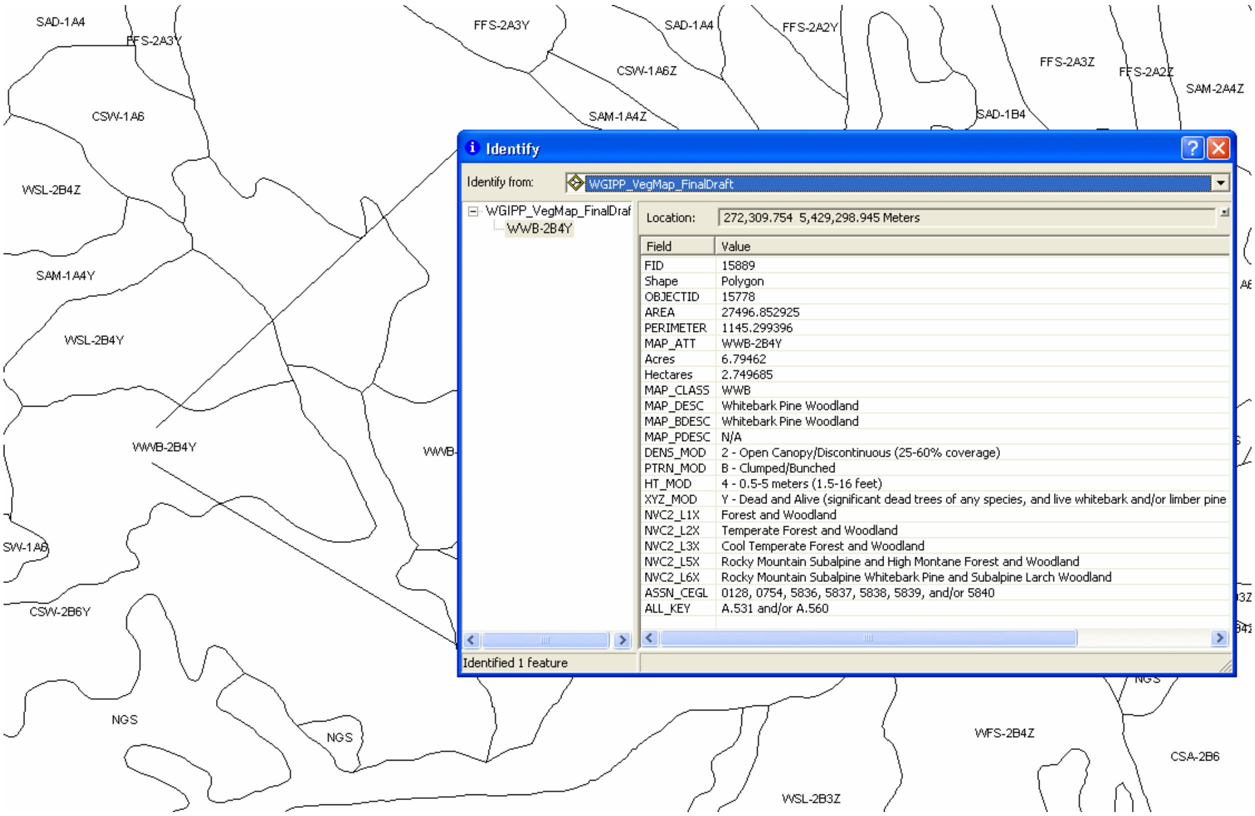

Figure 40. Map polygon with map attribute table assignment.

We produced the attribute table in spreadsheet format (dBASE IV) with information relating to the attribute items listed in Table 15. Using ArcGIS, we then joined the attribute table to the map coverage's table using the MAP_ATT item as the common attribute item. In addition to the attribute items listed in Table 15, default items from ArcInfo are also included in the final map coverages (e.g., perimeter, area, and polygon identification numbers). We used ArcGIS to produce the ArcInfo Export and Spatial Data Transfer Standard files of the map coverages. The map coverages are projected in UTM, Zone 12, using NAD83.

It is intended at a later date to incorporate the map coverage into an ArcGIS Geodatabase, which will provide additional information to the map coverage via a lookup table. The lookup table will include crosswalks to (1) NVC association and alliance names, (2) Classification of Wetlands and Deepwater Habitats of the United States (Cowardin et al. 1979) as modified for the National Wetlands Inventory Mapping Convention, and (3) 2001 National Land Cover Database (NLCD; see Homer et al. 2004 for development use of NLCD 2001 for the United States; also see < www.mrlc.gov/nlcd_definitions.asp> for a listing of NLCD 2001 Land Cover Class Definition). The Geodatabase will also link the map coverage to other data sets, both internal and external to this project, providing easy access to a variety of interlocking data sets, and equipping resource managers and researchers with a powerful tool.

Table 15. Map attribute items of the Glacier National Park and Waterton Lakes National Park vegetation map coverages.

Map Item	Map Item Description	Examples
MAP_ATT	Map Class code with all applicable Physiognomic Modifier codes (project derived)	Ex 1: FCH-2B2 Ex 2: WFS-3C4Y Ex 3: HGL-1AX Ex 4: VCT
MAP_CLASS	Map Class code (project derived)	Ex 1: FCH Ex 2: WFS Ex 3: HWM Ex 4: VCT
MAP_DESC	Full Map Class name, Base and Phase names together (project derived)	Ex 1: Cedar - Hemlock Forest (mesic phase) Ex 2: Subalpine Fir - Engelmann Spruce Woodland Ex 3: Wet Meadow Herbaceous Ex 4: Cliff/Talus Sparse Vegetation
MAP_BDESC	Base Map Class name (project derived)	Ex 1: Cedar - Hemlock Forest Ex 2: Subalpine Fir - Engelmann Spruce Woodland Ex 3: Wet Meadow Herbaceous Ex 4: Cliff/Talus Sparse Vegetation
MAP_PDESC	Phase Map Class name (project derived)	Ex 1: mesic phase Ex 2: N/A Ex 3: N/A Ex 4: N/A
DENS_MOD	Coverage Density Physiognomic Modifier	Ex 1: 2 - Open Canopy/Discontinuous (25-60% coverage) Ex 2: 3 - Dispersed/Sparse Canopy (10-25% coverage) Ex 3: 1 - Closed Canopy/Continuous (60-100% coverage) Ex 4: N/A
PTRN_MOD	Coverage Pattern Physiognomic Modifier	Ex 1: B - Clumped/Bunched Ex 2: C - Gradational/Transitional Ex 3: A - Evenly Dispersed Ex 4: N/A
HT_MOD	Height Physiognomic Modifier	Ex 1: 2 - 15-30 meters (50-98 feet) Ex 2: 4 - 0.5-5 meters (1.5-16 feet) Ex 3: N/A Ex 4: N/A
XYZ_MOD	Whitebark and Limber Pine Habitat Component Modifier (project specific)	Ex 1: Y - Dead and Alive (significant dead trees of any species, and live whitebark and/or limber pine trees present within the polygon) Ex 2: N/A Ex 3: X - Dead (significant dead trees of any species present within the polygon; no live whitebark and/or limber pine trees) Ex 4: N/A
NVC2_L1X	Level 1 – Formation Class National Vegetation Classification (Version 2 - Draft)	Ex 1: Forest and Woodland Ex 2: Forest and Woodland Ex 3: Shrubland and Grassland Ex 4: Nonvascular and Sparse Vascular Vegetation

Map Item	Map Item Description	Examples
NVC2_L2X	Level 2 - Formation Subclass National Vegetation Classification (Version 2 - Draft)	Ex 1: Temperate Forest and Woodland Ex 2: Temperate Forest and Woodland Ex 3: Temperate and Boreal Grassland, Meadow, and Shrubland Ex 4: Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vascular Vegetation
NVC2_L3X	Level 3 - Formation National Vegetation Classification (Version 2 - Draft)	Ex 1: Cool Temperate Forest and Woodland Ex 2: Cool Temperate Forest and Woodland Ex 3: Temperate Grassland, Forb Meadow, and Shrubland Ex 4: Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation
NVC2_L5X	Level 5 - Macrogroup National Vegetation Classification (Version 2 - Draft)	Ex 1: Rocky Mountain Subalpine and High Montane Conifer Forest and Woodland Ex 2: Rocky Mountain Subalpine and High Montane Conifer Forest and Woodland Ex 3: Northern (Cool) Rocky Mountain - Vancouverian Montane Shrubland and Grassland Ex 4: Rocky Mountain Cliff, Scree, Talus, and Other Rock Vegetation
NVC2_L6X	Level 6 - Group National Vegetation Classification (Version 2 - Draft)	Ex 1: Rocky Mountain Cedar - Hemlock Rainforest Ex 2: Rocky Mountain Subalpine Mesic Conifer Forest and Woodland Ex 3: Rocky Mountain Montane Grassland Ex 4: Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation
ASSN_CEGL	Community Element Global code National Vegetation Classification (NatureServe)	Ex 1: CEGL000471, CEGL000473, CEGL000474, CEGL000476, CEGL000479, CEGL000488, CEGL000491, CEGL000493, CEGL000494, CEGL005930, and/or CEGL005931
		Ex 2: CEGL000317, CEGL000336, CEGL000340, CEGL000985, CEGL005823, CEGL005894, CEGL005895, CEGL005896, CEGL005897, CEGL005898, CEGL005914, CEGL005917, CEGL005920, and/or CEGL005925
		Ex 3: CEGL001065, CEGL001502, CEGL001503, CEGL001531, CEGL001533, CEGL001614, CEGL001623, CEGL001624, CEGL001625, CEGL001629, CEGL001659, CEGL001677, CEGL001898, CEGL005830, CEGL005856, CEGL005860, CEGL005861, CEGL005862, CEGL005864, CEGL005868, CEGL005869, CEGL005870, CEGL005874, and/or CEGL005875
		Ex 4: CEGL005833, CEGL005855, CEGL005863, CEGL005899, CEGL005900, CEGL005901, CEGL005902, CEGL005903, Park Special 1, and/or Park Special 5
ALL_KEY	Alliance Key code National Vegetation Classification (NatureServe)	Ex 1: A.145, A.166, A.174, and/or A.193
		Ex 2: A.164, A.168, A.177, A.559, and/or A.811
		Ex 3: A.913, A.1079, A.1251, A.1255, A.1265, A.1271, A.1313, A.1409, A.1534, A.2637, A.2639, A.2658, A.3535, and/or A.3562
		Ex 4: A.1603, A.2630, A.1625, A.2638, A.1534, A.2634, A.1632, and/or A.2635

Results

Map Classes

We developed 48 map classes (including a couple map class phases) to map Waterton-Glacier IPP and environs (Table 16). Of these 48 map classes, 42 represent vegetation types within the NVC. The other six map classes represent general land cover, either land use (e.g., road, village) or non-vegetated areas (e.g., lake, snowfield).

Of the 48 map classes, 47 were used to map GNP and environs, and 38 map classes were used to map WLNP and the adjoining Blood Indian Timber Limit (BITL). (Map classes not used for each mapping effort are noted in Table 16.)

Map Classes Representing NVC Vegetation Types

Of the 42 map classes representing NVC vegetation types, 21 of them represent vegetation types typically associated under the NVC Forest and Woodland Class, with 15 of them being fundamentally upland and six of them wetland. These 21 map classes represent all conifer, deciduous, and mixed conifer-deciduous forest and woodland types, yet also include the conifer krummholz shrublands found in the subalpine zone.

Another 15 map classes represent vegetation types typical of the NVC Shrubland and Grassland Class, with about half the map classes characterizing upland sites and the other half typifying wetland sites. Of these map classes, avalanche chutes and snow burial fields are represented. Likewise, dry prairie lands to deep-water marshes are also contained within this category of map classes. Lastly, this category includes map classes representing early successional growth of herbaceous/shrub/short tree types in response to recent (perhaps within 20 years of aerial photo date, depending on severity of disturbance) disturbances such as fire, mechanical harvest, bug and disease infestation, and blowdown.

One map class adds a unique characteristic to the area and represents vegetation types of the NVC Semi-Desert Scrub and Grassland Class, essentially the sagebrush shrub-herbaceous types. These remain separated from the Shrubland and Grassland Class since they are considered part of the cool semi-desert intermountain region, with life forms characteristic of semi-desert environments.

Three map classes are categorized with the NVC Polar and High Montane Vegetation Class. For the most part, these map classes represent vegetation types in the high country, and have >10% dwarf-shrub and/or herbaceous cover. In situations of <10% cover, another map class from the NVC Nonvascular and Sparse Vascular Vegetation Class represents the vegetation types.

One final vegetation map class is listed under the Agricultural Vegetation Class, representing cultivated lands as either row or close-grown crops. This map class is infrequent of Waterton-Glacier IPP.

Map Classes Representing Non-vegetation Units

Of the six map classes representing non-vegetation units, three of them map hydrological-type entities lacking vegetation, including glaciers/snowfields, rivers/streams, and lakes/ponds. The other three map classes, although they may contain vegetation as part of their unit, represent developed and cultural areas, including residential/commercial areas, quarries, and roads/railroads.

Table 16. Map classification for the Waterton-Glacier International Peace Park Vegetation Mapping Project; National Vegetation Classification Version 2 - Draft.

NVC Name	Map Code	Map Class Description
Forest and Woodland Class		
Temperate Forest and Woodland Subclass		
Cool Temperate Forest and Woodland Formation		
Rocky Mountain Subalpine and High Montane Forest and Woodland MacroGroup		
Rocky Mountain Subalpine Mesic Conifer Forest and Woodland Group		
	FFS	Subalpine Fir - Engelmann Spruce Forest
	WFS	Subalpine Fir - Engelmann Spruce Woodland
	SFK	Krummholz Shrubland
Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland Group		
	WWB	Whitebark Pine Woodland
	WSL	Subalpine Larch Woodland
Rocky Mountain Subboreal and Montane Conifer Forest Group		
	FLP	Lodgepole Pine Forest
	WLP	Lodgepole Pine Woodland
Rocky Mountain Subalpine (Cool) Deciduous Broadleaf and Mixed Forest Group		
	FAP	Poplar - Birch Forest
	FEP	Mixed Conifer - Deciduous Forest
Rocky Mountain Lower Montane Forest and Woodland MacroGroup		
Rocky Mountain Montane Limber Pine - Juniper Woodland Group		
	WLM	Limber Pine Woodland
Rocky Mountain Mesic Montane Conifer Forest Group		
	FDF	Douglas-fir Forest
	WDF	Douglas-fir Woodland
	FWL*	Western Larch Forest
Northern Rocky Mountain Ponderosa Pine Woodland Group		
	WPP*	Ponderosa Pine Woodland
Rocky Mountain Cedar - Hemlock Rainforest Group		
	FCH*	Cedar - Hemlock Forest (mesic phase)
Temperate Wetland Forest and Woodland Formation		
Rocky Mountain and Great Basin Wet Forest MacroGroup		
Northern Rocky Mountain Conifer Swamp and Riparian Forest Group		
	FCS*	Cedar - Hemlock Forest (wet phase)
Rocky Mountain Conifer Swamp and Riparian Forest Group		
	FPW*	Lodgepole Pine Wet Forest
	FSP	Engelmann Spruce Forest
	FSW	Engelmann Spruce - Wet Shrub Forest
Northern Rocky Mountain Montane Riparian Forest Group		
	FCW	Black Cottonwood Forest
	FWM	Mixed Conifer - Deciduous Wet Forest

NVC Name	Map Code	Map Class Description
Shrubland and Grassland Class		
Temperate and Boreal Grassland, Meadow, and Shrubland Subclass		
Temperate Grassland, Forb Meadow, and Shrubland Formation		
Northern (Cool) Rocky Mountain - Vancouverian Montane Shrubland and Grassland MacroGroup		
Northern Rocky Mountain Avalanche Chute Shrubland Group		
	SAD	Deciduous Shrubland: Avalanche/Snow Burial
	SAM	Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial
Northern Rocky Mountain Lower Montane Deciduous Shrubland Group		
	SDS	Deciduous Shrubland: Dry - Mesic
Rocky Mountain Montane Grassland Group		
	HGL	Grassland Herbaceous
Rocky Mountain Successional Vegetation MacroGroup		
Rocky Mountain Early Successional Forest, Shrubland, and Forb Meadow Group		
	FCR*	Mixed Conifer Regenerate Forest
	SMR	Mixed Regenerate Shrubland
	VBA*	Burned Vegetation: Bare Soil
Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation		
Western North America Freshwater Shrub, Marsh, and Wet Meadow MacroGroup		
Rocky Mountain Subalpine and Montane Riparian Shrubland Group		
	SWL	Deciduous Wet Shrubland
Rocky Mountain Wet Meadow and Snowbed Group		
	CSW	Dwarf-shrub/Herbaceous Complex: Mesic - Wet
Western North America Emergent Marsh Group		
	HWM	Wet Meadow Herbaceous
	HSF	Semi-permanently Flooded Herbaceous
	HPF	Permanently Flooded Herbaceous
Rocky Mountain Shoreline Vegetation Group		
	HES	Exposed Shoreline Herbaceous: Pioneering Vegetation
	VEE	Exposed Shoreline Sparse Vegetation (eroded embankment phase)
	VSL	Exposed Shoreline Sparse Vegetation (wet riparian/basin phase)
Semi-Desert Scrub and Grassland Class		
Cool Semi-Desert Scrub and Grassland Subclass		
Cool Semi-Desert Scrub and Grassland Formation		
Northern Great Basin Shrub Steppe and Grassland MacroGroup		
Inter-Mountain Basin Montane Sagebrush Steppe Group		
	HSS*	Sagebrush - Fescue Shrub Herbaceous
Polar and High Montane Vegetation Class		
Temperate and Boreal Alpine Vegetation Subclass		
Alpine Scrub, Forb Meadow, and Grassland Formation		
Rocky Mountain Alpine Scrub, Forb Meadow, and Grassland MacroGroup		

NVC Name	Map Code	Map Class Description
Rocky Mountain Alpine Dry Scrub and Fell-field Group		
	DBB**	Bearberry Dwarf-shrubland
	DWD	White Dryad Dwarf-shrubland
Rocky Mountain Alpine Meadow Group		
	CSA	Dwarf-shrub/Herbaceous Complex: Dry - Mesic
Nonvascular and Sparse Vascular Vegetation Class		
Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vascular Vegetation Subclass		
Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation		
Rocky Mountain Cliff, Scree, Talus, and Other Rock Vegetation MacroGroup		
Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation Group		
	VCT	Cliff/Talus Sparse Vegetation
Agricultural Vegetation Class		
Herbaceous Agricultural Vegetation Subclass		
Cultivated Crop Formation		
Temperate and Tropical Row Crop/Close Grown Crop MacroGroup		
Temperate Row Crop/Close Grown Crop Group		
	XHC*	Hayfield/Cropland
Non-vegetated Land (non-NVC Class)		
Terrestrial Natural Non-vegetated Land (non-NVC Subclass)		
Glacier, Ice, and Snowfield (non-NVC Formation)		
Perennial Glacier and Snowfield (non-NVC MacroGroup)		
Mountain Perennial Glacier and Snowfield (non-NVC Group)		
	NGS	Glacier/Snowfield
Water-body (non-NVC Formation)		
Open Water-body (non-NVC MacroGroup)		
Open Water Stream/River and Lake/Pond (non-NVC Group)		
	NST	Stream/River
	NLP	Natural/Artificial Lake/Pond
Terrestrial Cultural Non-vegetated Land (non-NVC Subclass)		
Developed Land (non-NVC Formation)		
Developed and Other Cultural Area (non-NVC MacroGroup)		
Developed Area (non-NVC Group)		
	NRC	Residential/Commercial Area
Other Cultural Area (non-NVC Group)		
	NQR*	Quarry
	NRR	Road/Railroad

* Map Classes not used for mapping of Waterton Lakes National Park and environs
** Map Class not used for mapping of Glacier National Park and environs

Map Classification Descriptions

In addition to providing descriptions to each NVC plant community (Appendix G: Descriptions to Plant Associations of Waterton-Glacier IPP), we also developed descriptions for each map class to

- describe each map class from a photointerpretation perspective so the user may better understand how and why the map coverage was made,
- describe the link between each map class and the NVCS plant community it represents,
- provide a ground photo image for each map class, and
- provide a quick reference to AA results.

Appendix J: Map Classification Descriptions of Waterton-Glacier IPP gives descriptions to each map class we used in mapping Waterton-Glacier IPP and environs. This appendix includes map classes (and their phases) representing both vegetation types of the NVC and non-vegetated units. It provides a summary of the plant communities that each map class represents, including a quick-reference crosswalk table.

Map Coverage Summary Reports

Table 17 provides a summary report extracted from a seamless merge of the GNP and WLNP spatial database layers, summarizing frequency, area, and average polygon size for each map class. Table 18 provides a similar report of the same layer, however summarizing at the NVC (Vr2X) Class and Formation levels. Summary reports of the same information are provided for the individual spatial database layers of GNP and WLNP in Tables 19 (by map class) and 20 (by Class and Formation). These summaries represent all the lands within the established project boundary, including the environs.

Below are some general observations and inferences from a quick study of these summary reports. Although many more inferences can be made, these are provided to show an example of how one can begin to analyze the spatial database maps and glean information from them. By deriving more complex summary reports from the map layers themselves (such as employing the physiognomic modifiers - coverage, pattern, and height), or even introducing other spatial database layers to extract out finer details, one can make further deductions regarding vegetation and its ecology.

Table 17. Area report of the combined vegetation map coverage for Waterton-Glacier International Peace Park (summarized by each map class).

NVC (Vr2X)	Map Code	Map Class Description	Waterton-Glacier IPP Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Forest and Woodland Class							
Temperate Forest and Woodland Subclass							
Cool Temperate Forest and Woodland Formation							
Rocky Mountain Subalpine and High Montane Forest and Woodland MacroGroup							
Rocky Mountain Subalpine Mesic Conifer Forest and Woodland Group							
	FFS	Subalpine Fir - Engelmann Spruce Forest	11,200	113,609.4	10.1	280,734.9	25.1
	WFS	Subalpine Fir - Engelmann Spruce Woodland	8,527	33,099.7	3.9	81,791.2	9.6
	SFK	Krummholz Shrubland	4,636	10,356.3	2.2	25,591.0	5.5
Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland Group							
	WWB	Whitebark Pine Woodland	3,653	25,945.3	7.1	64,112.3	17.6
	WSL	Subalpine Larch Woodland	592	2,864.5	4.8	7,078.3	12.0
Rocky Mountain Subboreal and Montane Conifer Forest Group							

NVC (Vr2X)	Map Code	Map Class Description	Waterton-Glacier IPP Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
	FLP	Lodgepole Pine Forest	6,171	37,138.5	6.0	91,771.2	14.9
	WLP	Lodgepole Pine Woodland	467	868.3	1.9	2,145.6	4.6
Rocky Mountain Subalpine (Cool) Deciduous Broadleaf and Mixed Forest Group							
	FAP	Poplar - Birch Forest	2,702	7,764.2	2.9	19,185.8	7.1
	FEP	Mixed Conifer - Deciduous Forest	4,482	15,252.1	3.4	37,688.7	8.4
Rocky Mountain Lower Montane Forest and Woodland MacroGroup							
Rocky Mountain Montane Limber Pine - Juniper Woodland Group							
	WLM	Limber Pine Woodland	302	967.3	3.2	2,390.2	7.9
Rocky Mountain Mesic Montane Conifer Forest Group							
	FDF	Douglas-fir Forest	4,601	27,761.8	6.0	68,601.0	14.9
	WDF	Douglas-fir Woodland	4,810	14,334.1	3.0	35,420.3	7.4
	FWL	Western Larch Forest	2,953	20,980.3	7.1	51,843.5	17.6
Northern Rocky Mountain Ponderosa Pine Woodland Group							
	WPP	Ponderosa Pine Woodland	53	270.9	5.1	669.5	12.6
Rocky Mountain Cedar - Hemlock Rainforest Group							
	FCH	Cedar - Hemlock Forest (mesic phase)	309	8,359.5	27.1	20,656.7	66.9
Temperate Wetland Forest and Woodland Formation							
Rocky Mountain and Great Basin Wet Forest MacroGroup							
Northern Rocky Mountain Conifer Swamp and Riparian Forest Group							
	FCS	Cedar - Hemlock Forest (wet phase)	60	222.3	3.7	549.3	9.2
Rocky Mountain Conifer Swamp and Riparian Forest Group							
	FPW	Lodgepole Pine Wet Forest	10	14.9	1.5	36.7	3.7
	FSP	Engelmann Spruce Forest	1,176	2,386.8	2.0	5,897.9	5.0
	FSW	Engelmann Spruce - Wet Shrub Forest	1,141	2,314.1	2.0	5,718.2	5.0
Northern Rocky Mountain Montane Riparian Forest Group							
	FCW	Black Cottonwood Forest	1,042	1,659.8	1.6	4,101.5	3.9
	FWM	Mixed Conifer - Deciduous Wet Forest	1,203	2,679.2	2.2	6,620.4	5.5
Shrubland and Grassland Class							
Temperate and Boreal Grassland, Meadow, and Shrubland Subclass							
Temperate Grassland, Forb Meadow, and Shrubland Formation							
Northern (Cool) Rocky Mountain - Vancouverian Montane Shrubland and Grassland MacroGroup							
Northern Rocky Mountain Avalanche Chute Shrubland Group							
	SAD	Deciduous Shrubland: Avalanche/Snow Burial	4,189	9,496.8	2.3	23,467.1	5.6
	SAM	Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial	4,198	11,149.8	2.7	27,551.7	6.6
Northern Rocky Mountain Lower Montane Deciduous Shrubland Group							
	SDS	Deciduous Shrubland: Dry - Mesic	1,851	2,290.1	1.2	5,659.1	3.1
Rocky Mountain Montane Grassland Group							
	HGL	Grassland Herbaceous	2,856	6,959.7	2.4	17,197.7	6.0
Rocky Mountain Successional Vegetation MacroGroup							
Rocky Mountain Early Successional Forest, Shrubland, and Forb Meadow Group							
	FCR	Mixed Conifer Regenerate Forest	17	135.8	8.0	335.5	19.7
	SMR	Mixed Regenerate Shrubland	1,934	9,824.6	5.1	24,277.1	12.6

NVC (Vr2X)	Map Code	Map Class Description	Waterton-Glacier IPP Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
	VBA	Burned Vegetation: Bare Soil	76	1,491.9	19.6	3,686.5	48.5
Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation							
Western North America Freshwater Shrub, Marsh, and Wet Meadow MacroGroup							
Rocky Mountain Subalpine and Montane Riparian Shrubland Group							
	SWL	Deciduous Wet Shrubland	2,356	3,274.8	1.4	8,092.1	3.4
Rocky Mountain Wet Meadow and Snowbed Group							
	CSW	Dwarf-shrub/Herbaceous Complex: Mesic - Wet	4,714	8,348.1	1.8	20,628.5	4.4
Western North America Emergent Marsh Group							
	HWM	Wet Meadow Herbaceous	1,296	1,123.0	0.9	2,775.1	2.1
	HSF	Semi-permanently Flooded Herbaceous	54	80.5	1.5	199.0	3.7
	HPF	Permanently Flooded Herbaceous	73	112.0	1.5	276.7	3.8
Rocky Mountain Shoreline Vegetation Group							
	HES	Exposed Shoreline Herbaceous: Pioneering Vegetation	658	583.9	0.9	1,442.7	2.2
	VEE	Exposed Shoreline Sparse Vegetation (eroded embankment phase)	334	179.1	0.5	442.7	1.3
	VSL	Exposed Shoreline Sparse Vegetation (wet riparian/basin phase)	886	943.6	1.1	2,331.6	2.6
Semi-Desert Scrub and Grassland Class							
Cool Semi-Desert Scrub and Grassland Subclass							
Cool Semi-Desert Scrub and Grassland Formation							
Northern Great Basin Shrub Steppe and Grassland MacroGroup							
Inter-Mountain Basin Montane Sagebrush Steppe Group							
	HSS	Sagebrush - Fescue Shrub Herbaceous	101	131.7	1.3	325.4	3.2
Polar and High Montane Vegetation Class							
Temperate and Boreal Alpine Vegetation Subclass							
Alpine Scrub, Forb Meadow, and Grassland Formation							
Rocky Mountain Alpine Scrub, Forb Meadow, and Grassland MacroGroup							
Rocky Mountain Alpine Dry Scrub and Fell-field Group							
	DBB	Bearberry Dwarf-shrubland	46	145.6	3.2	359.7	7.8
	DWD	White Dryad Dwarf-shrubland	358	1,574.4	4.4	3,890.5	10.9
Rocky Mountain Alpine Meadow Group							
	CSA	Dwarf-shrub/Herbaceous Complex: Dry - Mesic	12,036	48,811.4	4.1	120,615.6	10.0
Nonvascular and Sparse Vascular Vegetation Class							
Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vascular Vegetation Subclass							
Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation							
Rocky Mountain Cliff, Scree, Talus, and Other Rock Vegetation MacroGroup							
Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation Group							
	VCT	Cliff/Talus Sparse Vegetation	3,991	33,561.0	8.4	82,931.0	20.8
Agricultural Vegetation Class							
Herbaceous Agricultural Vegetation Subclass							
Cultivated Crop Formation							
Temperate and Tropical Row Crop/Close Grown Crop MacroGroup							
Temperate Row Crop/Close Grown Crop Group							
	XHC	Hayfield/Cropland	10	123.2	12.3	304.5	30.5

NVC (Vr2X)	Map Code	Map Class Description	Waterton-Glacier IPP Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Non-vegetated Land (non-NVC Class)							
Terrestrial Natural Non-vegetated Land (non-NVC Subclass)							
Glacier, Ice, and Snowfield (non-NVC Formation)							
Perennial Glacier and Snowfield (non-NVC MacroGroup)							
Mountain Perennial Glacier and Snowfield (non-NVC Group)							
	NGS	Glacier/Snowfield	6,147	8,346.0	1.4	20,623.5	3.4
Water-body (non-NVC Formation)							
Open Water-body (non-NVC MacroGroup)							
Open Water Stream/River and Lake/Pond (non-NVC Group)							
	NST	Stream/River	119	2,163.3	18.2	5,345.7	44.9
	NLP	Natural/Artificial Lake/Pond	941	12,992.7	13.8	32,105.7	34.1
Terrestrial Cultural Non-vegetated Land (non-NVC Subclass)							
Developed Land (non-NVC Formation)							
Developed and Other Cultural Area (non-NVC MacroGroup)							
Developed Area (non-NVC Group)							
	NRC	Residential/Commercial Area	425	930.1	2.2	2,298.3	5.4
Other Cultural Area (non-NVC Group)							
	NQR	Quarry	14	39.7	2.8	98.0	7.0
	NRR	Road/Railroad	63	1,180.6	18.7	2,917.3	46.3
		GRAND TOTALS	**109,833**	**494,842.6**	**4.5**	**1,222,782.8**	**11.1**

* The Waterton-Glacier International Peace Park Vegetation Map includes 36,846.3 ha (91,049.4 ac) of environs external to Waterton-Glacier International Peace Park (7.8% of the map)

Table 18. Area report of the combined vegetation map coverage for Waterton-Glacier International Peace Park (summarized by National Vegetation Classification Version 2X Class and Formation levels).

NVC (Vr2X) Class and Formation Vegetation	Waterton-Glacier IPP Vegetation Map*				
	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Forest and Woodland Class	**60,090**	**328,849.2**	**5.5**	**812,604.1**	**13.5**
Cool Temperate Forest and Woodland Formation	*55,458*	*319,572.2*	*5.8*	*789,680.0*	*14.2*
Temperate Wetland Forest and Woodland Formation	*4,632*	*9,277.0*	*2.0*	*22,924.1*	*4.9*
Shrubland and Grassland Class	**25,492**	**55,993.6**	**2.2**	**138,363.3**	**5.4**
Temperate Grassland, Forb Meadow, and Shrubland Formation	*15,121*	*41,348.7*	*2.7*	*102,174.8*	*6.8*
Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation	*10,371*	*14,644.9*	*1.4*	*36,188.4*	*3.5*
Semi-Desert Scrub and Grassland Class	**101**	**131.7**	**1.3**	**325.4**	**3.2**
Cool Semi-Desert Scrub and Grassland Formation	*101*	*131.7*	*1.3*	*325.4*	*3.2*
Polar and High Montane Vegetation Class	**12,440**	**50,531.4**	**4.1**	**124,865.9**	**10.0**
Alpine Scrub, Forb Meadow, and Grassland Formation	*12,440*	*50,531.4*	*4.1*	*124,865.9*	*10.0*
Nonvascular and Sparse Vascular Vegetation Class	**3,991**	**33,561.0**	**8.4**	**82,931.0**	**20.8**
Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation	*3,991*	*33,561.0*	*8.4*	*82,931.0*	*20.8*
Agricultural Vegetation Class	**10**	**123.2**	**12.3**	**304.5**	**30.5**
Cultivated Crop Formation	*10*	*123.2*	*12.3*	*304.5*	*30.5*
NVC VEGETATION TOTALS	**102,124**	**469,190.2**	**4.6**	**1,159,394.3**	**11.4**

Table 19. Area report of the vegetation map coverages for Glacier National Park and Waterton Lakes National Park (summarized by each map class).

NVC (Vr2X)	Map Code	Map Class Description	Glacier National Park Vegetation Map					Waterton Lakes National Park Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Forest and Woodland Class												
Temperate Forest and Woodland Subclass												
Cool Temperate Forest and Woodland Formation												
Rocky Mountain Subalpine and High Montane Forest and Woodland MacroGroup												
Rocky Mountain Subalpine Mesic Conifer Forest and Woodland Group												
	FFS	Subalpine Fir - Engelmann Spruce Forest	10,202	103,725.2	10.2	256,310.7	25.1	998	9,884.1	9.9	24,424.3	24.5
	WFS	Subalpine Fir - Engelmann Spruce Woodland	7,710	30,603.5	4.0	75,622.8	9.8	817	2,496.3	3.1	6,168.5	7.6
	SFK	Krummholz Shrubland	4,047	9,394.5	2.3	23,214.3	5.7	589	961.8	1.6	2,376.6	4.0
Rocky Mountain Subalpine Whitebark Pine and Subalpine Larch Woodland Group												
	WWB	Whitebark Pine Woodland	2,950	21,750.9	7.4	53,747.6	18.2	703	4,194.4	6.0	10,364.7	14.7
	WSL	Subalpine Larch Woodland	325	1,659.3	5.1	4,100.2	12.6	267	1,205.2	4.5	2,978.1	11.2
Rocky Mountain Subboreal and Montane Conifer Forest Group												
	FLP	Lodgepole Pine Forest	5,673	33,951.3	6.0	83,895.5	14.8	498	3,187.2	6.4	7,875.7	15.8
	WLP	Lodgepole Pine Woodland	418	760.3	1.8	1,878.7	4.5	49	108.0	2.2	267.0	5.4
Rocky Mountain Subalpine (Cool) Deciduous Broadleaf and Mixed Forest Group												
	FAP	Poplar - Birch Forest	1,993	4,686.3	2.4	11,580.1	5.8	709	3,077.9	4.3	7,605.7	10.7
	FEP	Mixed Conifer - Deciduous Forest	4,078	13,715.1	3.4	33,890.7	8.3	404	1,537.0	3.8	3,798.0	9.4
Rocky Mountain Lower Montane Forest and Woodland MacroGroup												
Rocky Mountain Montane Limber Pine - Juniper Woodland Group												
	WLM	Limber Pine Woodland	100	133.9	1.3	330.9	3.3	202	833.4	4.1	2,059.3	10.2
Rocky Mountain Mesic Montane Conifer Forest Group												
	FDF	Douglas-fir Forest	4,240	25,147.1	5.9	62,139.8	14.7	361	2,614.7	7.2	6,461.2	17.9
	WDF	Douglas-fir Woodland	4,325	12,764.6	3.0	31,542.1	7.3	485	1,569.5	3.2	3,878.2	8.0
	FWL	Western Larch Forest	2,953	20,980.3	7.1	51,843.5	17.6	0	0.0	0.0	0.0	0.0
Northern Rocky Mountain Ponderosa Pine Woodland Group												
	WPP	Ponderosa Pine Woodland	53	270.9	5.1	669.5	12.6	0	0.0	0.0	0.0	0.0
Rocky Mountain Cedar - Hemlock Rainforest Group												
	FCH	Cedar - Hemlock Forest (mesic phase)	309	8,359.5	27.1	20,656.7	66.9	0	0.0	0.0	0.0	0.0
Temperate Wetland Forest and Woodland Formation												
Rocky Mountain and Great Basin Wet Forest MacroGroup												

NVC (Vr2X)	Map Code	Map Class Description	Glacier National Park Vegetation Map					Waterton Lakes National Park Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Northern Rocky Mountain Conifer Swamp and Riparian Forest Group												
	FCS	Cedar - Hemlock Forest (wet phase)	60	222.3	3.7	549.3	9.2	0	0.0	0.0	0.0	0.0
Rocky Mountain Conifer Swamp and Riparian Forest Group												
	FPW	Lodgepole Pine Wet Forest	10	14.9	1.5	36.7	3.7	0	0.0	0.0	0.0	0.0
	FSP	Engelmann Spruce Forest	1,080	2,182.8	2.0	5,393.8	5.0	96	204.0	2.1	504.2	5.3
	FSW	Engelmann Spruce - Wet Shrub Forest	1,111	2,259.6	2.0	5,583.5	5.0	30	54.5	1.8	134.7	4.5
Northern Rocky Mountain Montane Riparian Forest Group												
	FCW	Black Cottonwood Forest	956	1,190.1	1.2	2,940.9	3.1	86	469.7	5.5	1,160.6	13.5
	FWM	Mixed Conifer - Deciduous Wet Forest	1,201	2,675.6	2.2	6,611.5	5.5	2	3.6	1.8	9.0	4.5
Shrubland and Grassland Class												
Temperate and Boreal Grassland, Meadow, and Shrubland Subclass												
Temperate Grassland, Forb Meadow, and Shrubland Formation												
Northern (Cool) Rocky Mountain - Vancouverian Montane Shrubland and Grassland MacroGroup												
Northern Rocky Mountain Avalanche Chute Shrubland Group												
	SAD	Deciduous Shrubland: Avalanche/Snow Burial	3,929	9,069.5	2.3	22,411.2	5.7	260	427.3	1.6	1,055.9	4.1
	SAM	Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial	3,972	10,739.5	2.7	26,537.8	6.7	226	410.3	1.8	1,013.9	4.5
Northern Rocky Mountain Lower Montane Deciduous Shrubland Group												
	SDS	Deciduous Shrubland: Dry - Mesic	1,416	1,865.5	1.3	4,609.9	3.3	435	424.6	1.0	1,049.2	2.4
Rocky Mountain Montane Grassland Group												
	HGL	Grassland Herbaceous	2,235	3,893.4	1.7	9,620.8	4.3	621	3,066.3	4.9	7,577.0	12.2
Rocky Mountain Successional Vegetation MacroGroup												
Rocky Mountain Early Successional Forest, Shrubland, and Forb Meadow Group												
	FCR	Mixed Conifer Regenerate Forest	17	135.8	8.0	335.5	19.7	0	0.0	0.0	0.0	0.0
	SMR	Mixed Regenerate Shrubland	1,799	8,712.8	4.8	21,529.7	12.0	135	1,111.8	8.2	2,747.4	20.4
	VBA	Burned Vegetation: Bare Soil	76	1,491.9	19.6	3,686.5	48.5	0	0.0	0.0	0.0	0.0
Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation												
Western North America Freshwater Shrub, Marsh, and Wet Meadow MacroGroup												
Rocky Mountain Subalpine and Montane Riparian Shrubland Group												
	SWL	Deciduous Wet Shrubland	2,169	2,763.1	1.3	6,827.7	3.1	187	511.7	2.7	1,264.5	6.8
Rocky Mountain Wet Meadow and Snowbed Group												
	CSW	Dwarf-shrub/Herbaceous Complex: Mesic - Wet	4,542	8,170.4	1.8	20,189.6	4.4	172	177.6	1.0	438.9	2.6

NVC (Vr2X)	Map Code	Map Class Description	Glacier National Park Vegetation Map					Waterton Lakes National Park Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Western North America Emergent Marsh Group												
	HWM	Wet Meadow Herbaceous	1,171	957.1	0.8	2,364.9	2.0	125	166.0	1.3	410.1	3.3
	HSF	Semi-permanently Flooded Herbaceous	42	32.4	0.8	80.0	1.9	12	48.1	4.0	119.0	9.9
	HPF	Permanently Flooded Herbaceous	42	50.2	1.2	124.0	3.0	31	61.8	2.0	152.7	4.9
Rocky Mountain Shoreline Vegetation Group												
	HES	Exposed Shoreline Herbaceous: Pioneering Vegetation	586	443.0	0.8	1,094.7	1.9	72	140.9	2.0	348.1	4.8
	VEE	Exposed Shoreline Sparse Vegetation (eroded embankment phase)	306	165.7	0.5	409.3	1.3	28	13.5	0.5	33.3	1.2
	VSL	Exposed Shoreline Sparse Vegetation (wet riparian/basin phase)	787	693.0	0.9	1,712.5	2.2	99	250.5	2.5	619.1	6.3
Semi-Desert Scrub and Grassland Class												
Cool Semi-Desert Scrub and Grassland Subclass												
Cool Semi-Desert Scrub and Grassland Formation												
Northern Great Basin Shrub Steppe and Grassland MacroGroup												
Inter-Mountain Basin Montane Sagebrush Steppe Group												
	HSS	Sagebrush - Fescue Shrub Herbaceous	101	131.7	1.3	325.4	3.2	0	0.0	0.0	0.0	0.0
Polar and High Montane Vegetation Class												
Temperate and Boreal Alpine Vegetation Subclass												
Alpine Scrub, Forb Meadow, and Grassland Formation												
Rocky Mountain Alpine Scrub, Forb Meadow, and Grassland MacroGroup												
Rocky Mountain Alpine Dry Scrub and Fell-field Group												
	DBB	Bearberry Dwarf-shrubland	0	0.0	0.0	0.0	0.0	46	145.6	3.2	359.7	7.8
	DWD	White Dryad Dwarf-shrubland	343	1,503.4	4.4	3,715.1	10.8	15	71.0	4.7	175.4	11.7
Rocky Mountain Alpine Meadow Group												
	CSA	Dwarf-shrub/Herbaceous Complex: Dry - Mesic	10,262	42,432.0	4.1	104,851.9	10.2	1,774	6,379.4	3.6	15,763.8	8.9
Nonvascular and Sparse Vascular Vegetation Class												
Mediterranean, Temperate, and Boreal Nonvascular and Sparse Vascular Vegetation Subclass												
Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation												
Rocky Mountain Cliff, Scree, Talus, and Other Rock Vegetation MacroGroup												
Rocky Mountain Alpine Cliff, Scree, and Other Rock Vegetation Group												
	VCT	Cliff/Talus Sparse Vegetation	3,753	29,575.8	7.9	73,083.3	19.5	238	3,985.2	16.7	9,847.7	41.4
Agricultural Vegetation Class												

NVC (Vr2X)	Map Code	Map Class Description	Glacier National Park Vegetation Map					Waterton Lakes National Park Vegetation Map				
			Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Herbaceous Agricultural Vegetation Subclass												
Cultivated Crop Formation												
Temperate and Tropical Row Crop/Close Grown Crop MacroGroup												
Temperate Row Crop/Close Grown Crop Group												
	XHC	Hayfield/Cropland	10	123.2	12.3	304.5	30.5	0	0.0	0.0	0.0	0.0
Non-vegetated Land (non-NVC Class)												
Terrestrial Natural Non-vegetated Land (non-NVC Subclass)												
Glacier, Ice, and Snowfield (non-NVC Formation)												
Perennial Glacier and Snowfield (non-NVC MacroGroup)												
Mountain Perennial Glacier and Snowfield (non-NVC Group)												
	NGS	Glacier/Snowfield	5,891	8,180.6	1.4	20,214.7	3.4	256	165.4	0.6	408.8	1.6
Water-body (non-NVC Formation)												
Open Water-body (non-NVC MacroGroup)												
Open Water Stream/River and Lake/Pond (non-NVC Group)												
	NST	Stream/River	103	2,058.2	20.0	5,086.0	49.4	16	105.1	6.6	259.7	16.2
	NLP	Natural/Artificial Lake/Pond	852	11,499.7	13.5	28,416.3	33.4	89	1,493.0	16.8	3,689.4	41.5
Terrestrial Cultural Non-vegetated Land (non-NVC Subclass)												
Developed Land (non-NVC Formation)												
Developed and Other Cultural Area (non-NVC MacroGroup)												
Developed Area (non-NVC Group)												
	NRC	Residential/Commercial Area	410	782.6	1.9	1,933.9	4.7	15	147.5	9.8	364.4	24.3
Other Cultural Area (non-NVC Group)												
	NQR	Quarry	14	39.7	2.8	98.0	7.0	0	0.0	0.0	0.0	0.0
	NRR	Road/Railroad	53	1,013.4	19.1	2,504.0	47.2	10	167.2	16.7	413.2	41.3
		GRAND TOTALS	**98,675**	**442,971.4**	**4.5**	**1,094,606.1**	**11.1**	**11,158**	**51,871.2**	**4.6**	**128,176.6**	**11.5**

** The Glacier National Park Vegetation Map includes 34,915.6 ha (86,278.3 ac) of environs area external to Glacier National Park (7.9% of the map)

*** The Waterton Lakes National Park Vegetation Map includes 1,930.7 ha (4,771.1 ac) of the Blood Indian Timber Limit (3.7% of the map)

Table 20. Area report of the vegetation map coverages for Glacier National Park and Waterton Lakes National Park (summarized by National Vegetation Classification Version 2X Class and Formation levels).

Summaries of NVC (Vr2X) Class and Formation Vegetation	Glacier National Park Vegetation Map**					Waterton-Glacier IPP Vegetation Map***				
	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)	Freq	Area (Ha)	Ave (Ha)	Area (Ac)	Ave (Ac)
Forest and Woodland Class	**53,794**	**296,447.9**	**5.5**	**732,538.6**	**13.6**	**6,296**	**32,401.4**	**5.1**	**80,065.5**	**12.7**
Cool Temperate Forest and Woodland Formation	*49,376*	*287,902.7*	*5.8*	*711,423.0*	*14.4*	*6,082*	*31,669.5*	*5.2*	*78,257.1*	*12.9*
Temperate Wetland Forest and Woodland Formation	*4,418*	*8,545.2*	*1.9*	*21,115.7*	*4.8*	*214*	*731.8*	*3.4*	*1,808.4*	*8.5*
Shrubland and Grassland Class	**23,089**	**49,183.2**	**2.1**	**121,534.3**	**5.3**	**2,403**	**6,810.5**	**2.8**	**16,829.0**	**7.0**
Temperate Grassland, Forb Meadow, and Shrubland Formation	*13,444*	*35,908.4*	*2.7*	*88,731.5*	*6.6*	*1,677*	*5,440.3*	*3.2*	*13,443.4*	*8.0*
Temperate and Boreal Wet Riparian, Freshwater Marsh, and Shrub Swamp Formation	*9,645*	*13,274.8*	*1.4*	*32,802.8*	*3.4*	*726*	*1,370.1*	*1.9*	*3,385.7*	*4.7*
Semi-Desert Scrub and Grassland Class	**101**	**131.7**	**1.3**	**325.4**	**3.2**	0	**0.0**	**0.0**	**0.0**	**0.0**
Cool Semi-Desert Scrub and Grassland Formation	*101*	*131.7*	*1.3*	*325.4*	*3.2*	*0*	*0.0*	*0.0*	*0.0*	*0.0*
Polar and High Montane Vegetation Class	**10,605**	**43,935.5**	**4.1**	**108,567.0**	**10.2**	**1,835**	**6,595.9**	**3.6**	**16,298.9**	**8.9**
Alpine Scrub, Forb Meadow, and Grassland Formation	*10,605*	*43,935.5*	*4.1*	*108,567.0*	*10.2*	*1,835*	*6,595.9*	*3.6*	*16,298.9*	*8.9*
Nonvascular and Sparse Vascular Vegetation Class	**3,753**	**29,575.8**	**7.9**	**73,083.3**	**19.5**	**238**	**3,985.2**	**16.7**	**9,847.7**	**41.4**
Temperate and Boreal Cliff, Scree, Talus, and Other Rock Vegetation Formation	*3,753*	*29,575.8*	*7.9*	*73,083.3*	*19.5*	*238*	*3,985.2*	*16.7*	*9,847.7*	*41.4*
Agricultural Vegetation Class	**10**	**123.2**	**12.3**	**304.5**	**30.5**	**0**	**0.0**	**0.0**	**0.0**	**0.0**
Cultivated Crop Formation	*10*	*123.2*	*12.3*	*304.5*	*30.5*	*0*	*0.0*	*0.0*	*0.0*	*0.0*
NVC VEGETATION TOTALS	**91,352**	**419,397.2**	**4.6**	**1,036,353.2**	**11.3**	**10,772**	**49,793.0**	**4.6**	**123,041.1**	**11.4**

Combined Waterton-Glacier IPP

Collectively, the combined spatial database layer (GNP and WLNP with associated environs) of Waterton-Glacier IPP are comprised of approximately 110,000 polygons covering about 495,000 ha, with an average polygon size of 4.5 ha. Map classes representing vegetation types comprise more than 102,000 polygons and cover more than 469,000 ha (93% of polygons, and 95% of area). The NVC Forest and Woodland Class comprise the majority of polygons and area covered, with about 61,000 polygons covering around 329,000 ha (55% of polygons, and 66% of area); the majority consists of upland forests and woodlands (92%). The Subalpine Fir - Engelmann Spruce Forest (FFS) map class is by far the largest map class, having more than 11,000 polygons and covering well over 113,000 ha (essentially a tenth of all polygons, and almost a quarter of the entire map area).

The non-vegetated landscape comprises only a small portion of the spatial database layer, consisting of approximately 7,700 polygons that comprise fewer than 26,000 ha (7% of all polygons, and just over 5% of the entire area). Of the non-vegetated map classes, two dominate: Glacier/Snowfield (NGS) and Natural/Artificial Lake/Pond (NLP). The NGS map class is presented more than 6,000 times in the combined layer, covering more than 8,000 ha. The average polygon size, however, is small; a mere 1.4 ha in size. The NLP map class, on the other hand, has a much larger average polygon size of 13.8 ha. Covering nearly 13,000 ha, the NLP map class is presented fewer than 950 times throughout the combined layer, even though it covers 50% of the entire non-vegetated landscape.

More than 92% of the combined spatial database layer is of Waterton-Glacier IPP, the remainder being lands outside of the park. Nearly 90% of both polygons and area mapped are of GNP and associated environs; WLNP and the BITL make up the rest.

Glacier National Park

The GNP spatial database layer is comprised of 98,675 polygons covering just over 442,970 ha, with an average polygon size of 4.5 ha. Of this, 408,056 ha (85.5%) is of GNP lands, the remainder is of environs. Map classes representing vegetation types comprise 91,352 polygons and cover 419,397 ha (92.6% of polygons, and 94.7% of area).

The GNP spatial database map essentially follows the same pattern as described above for the combined Waterton-Glacier IPP layer—the NVC Forest and Woodland Class essentially dominate the landscape, and the FFS map class occurs more frequently and covers more area than any other map class.

The Cedar - Hemlock Forest (mesic phase) (FCH) map class is presented only a few times (n = 309), but covers a large area per polygon relative to other map classes. Bolstering a large average area size of more than 27 ha, the FCH map class covers almost 8,400 ha; just fewer than 2% of the entire GNP coverage. This may seem somewhat insignificant. However, the cedar-hemlock types are restricted west of the CD and constrained mostly to the Lake McDonald basin, and therefore have significant occurrence within certain locations.

We encountered a similar situation with the Sagebrush - Fescue Shrub Herbaceous (HSS) map class, yet to a much smaller degree. The sagebrush plant communities are essentially restricted to the northwest corner of GNP, mostly in areas of Big Prairie and Round Prairie. Only 101 polygons were mapped of HSS, covering 131.7 ha; quite diminutive to the entire map coverage. Yet, we testify from experience in the field, where sagebrush is present, it often flourishes and encroaches into prairies. Therefore, HSS was mapped with as little as 10% cover to provide indication of sagebrush presence within the prairies.

The Ponderosa Pine Woodland (WPP) map class is another map class where we made fair effort to map aggressively because of its encroaching nature into prairie meadows. This map class also tends to occur in the northwest corner of GNP, where only 53 polygons were mapped covering an area of approximately 270.9 ha.

The Mixed Regenerate Shrubland (SMR) map class represents vegetation types in response to a recent disturbance, whether fire, mechanical harvest (in the environs to GNP), bug and disease infestation, or blowdown. More than 8,700 ha of land were mapped with this map class, signifying that only 2% of the landscape was in an early successional stage due to a recent disturbance at the time the aerial photographs were collected (August 1999). However, with the large number of fires at GNP since 1999, the amount of SMR has increased significantly, particularly in areas severely burned.

The amount of Lodgepole Pine Forest (FLP) revealed from the mapping results gives credence to fire disturbance over the past 100 years. FLP comprised almost 5,700 polygons covering nearly 34,000 ha. This is significant given that the provision for mapping FLP is when lodgepole pine is >75% relative dominance to other tree species in the stand. From mapping and field experience, we recall numerous FFS polygons having significant amounts of lodgepole pine, yet the forest was mapped as spruce-fir forest, even though a 3:1 ratio of lodgepole pine to spruce-fir may have existed.

Waterton Lakes National Park

The WLNP spatial database layer is comprised of 11,158 polygons covering just over 51,870 ha, again with an average polygon size of 4.5 ha. Of this, 49,942 ha (96.3%) of the mapped area is of WLNP lands, the remainder being of BITL lands. Map classes representing vegetation types comprise 10,772 polygons and cover 49,793 ha (96.5% of polygons, and 96.0% of area).

Again, the WLNP spatial database map essentially follows the same pattern as the combined Waterton-Glacier IPP layer—the NVC Forest and Woodland Class dominate the landscape, and the FFS map class occurs more frequently and covers more area than any other map class.

Although quite significant in the GNP layer, the Whitebark Pine Woodland (WWB) map class is perhaps even more significant in the WLNP layer. For example, the WWB map class in WLNP contains about 70% of the polygons and covers approximately 42% of area when compared to the FFS map class. In contrast with the GNP layer, the WWB map class contains about 29% of the polygons and covers approximately 21% of the area when compared to the FFS map class.

A similar assessment can be made of the Grassland Herbaceous (HGL) map class. In proportion to the area mapped, almost 6% of the map is HGL for the WLNP layer, whereas less than 1% of the map is HGL for the GNP layer. One can also derive from the summary report's average polygon size that grasslands in WLNP tend to be larger (average 4.9 ha) and more contiguous, as opposed to the smaller (1.7 ha) more broken polygons found in GNP.

Occurrences of Polygons Smaller than Conventional Minimum Mapping Units

The standard MMU used for mapping Waterton-Glacier IPP was 0.5 ha, which is the USGS-NPS VMP's standard MMU size. However, for various reasons, it became evident when studying the detailed area report of the vegetation spatial database layer that numerous polygons fall significantly below the MMU.

The primary reason these small polygons exist is due to the liberal application of the MMU during photointerpretation to reduce mapping omissions. This aggressive approach to mapping the MMU was to counteract inborn angle distortions of nonrectified aerial photos (those distortions making the actual size visually smaller on the aerial photo), and to provide a margin of error in manually estimating the variable scales ranging within an aerial photo due to extreme elevation changes from high ridges to valley bottoms (e.g., 1:15,840 at the mountain top to 1:24,000 in the valley bottom).

Another reason for the smaller polygons is because when the interpreted overlay becomes orthoreferenced and the software makes adjustments for angle distortions within the photo, polygons changed shape and many reduce in size—even below MMU. In fact, we even noticed several scenarios where a polygon collapses together and splits into two or three polygons once distortions were removed from the interpreted layer, making a polygon of standard MMU size into several polygons smaller than MMU. These are casualties of mapping mountainous environments on base mediums prior to orthorectifying.

Some occurrences of polygons smaller than the standard MMU were intended. Some polygons were mapped down to 0.25 ha, particularly when the vegetation class was unique to its immediate surroundings (e.g., a sedge wetland meadow within an upland conifer forest). Also, with the interest in glacier and snow, the Glacier/Snowfield (NGS) map class was easily mapped to 0.25 ha, particularly in the alpine.

We also established a secondary MMU of 2.0 ha for physiognomic changes in the vegetation within a particular map class polygon. With a close study of the vegetation database layer, however, one will notice polygons of differing physiognomic features within the same map class covering areas between 0.5–2.0 ha (e.g., WFS-2B4 vs. WFS-2B5, CSA-2B vs. CSA-3B). This seems an infringement to the secondary MMU convention, since both of these polygons needed to be >2.0 ha. This is explained however, because prior to vegetation classification analyses and descriptions, we often applied the standard MMU of 0.5 ha instead of the secondary MMU of 2.0 ha.

For example, the WFS-XX4 code (where X = any relevant value and 4 = short tree height) continues to represent spruce-fir woodland types, as we originally determined prior to the classification being complete. The WFS-XX5 code (where 5 = low shrub height), however, was later found to represent low-growing conifer shrublands, as we somewhat anticipated prior to the classification being complete. It was not until late in the mapping effort that the vegetation classification had confirmed this vegetation type as a separate map class. (We applied a special "5" height to the WFS map class to code polygons of krummholz-like conifers in anticipation of this.) Once classification analysis concluded that a krummholz shrubland existed, we globally changed the WFS-XX5 codes to a conifer shrubland map class SFK-XX5.

We initially thought the same situation may hold true for the CSA map class (CSA-2B vs. CSA-3B), however, it did not prove to be worthy of separating, as we had originally anticipated. After the vegetation classification was complete, separating CSA physiognomically by cover density (coded 2 as moderate vs. 3 as sparse) in the mapping presented nothing more than just varying densities. Another vegetation type was not discovered, and, since we already mapped such polygons <MMU, we determined to keep them in the vegetation map coverage.

Vegetation Spatial Database Presentation

Figure 41 presents the map coverage produced from Waterton-Glacier IPP Vegetation Mapping Project. The finest level of map (the map attribute codes consisting of map classes and physiognomic modifiers) is too detailed to present, therefore the map in Figure 41 is generalized to show map classes organized by NVCvr2x.

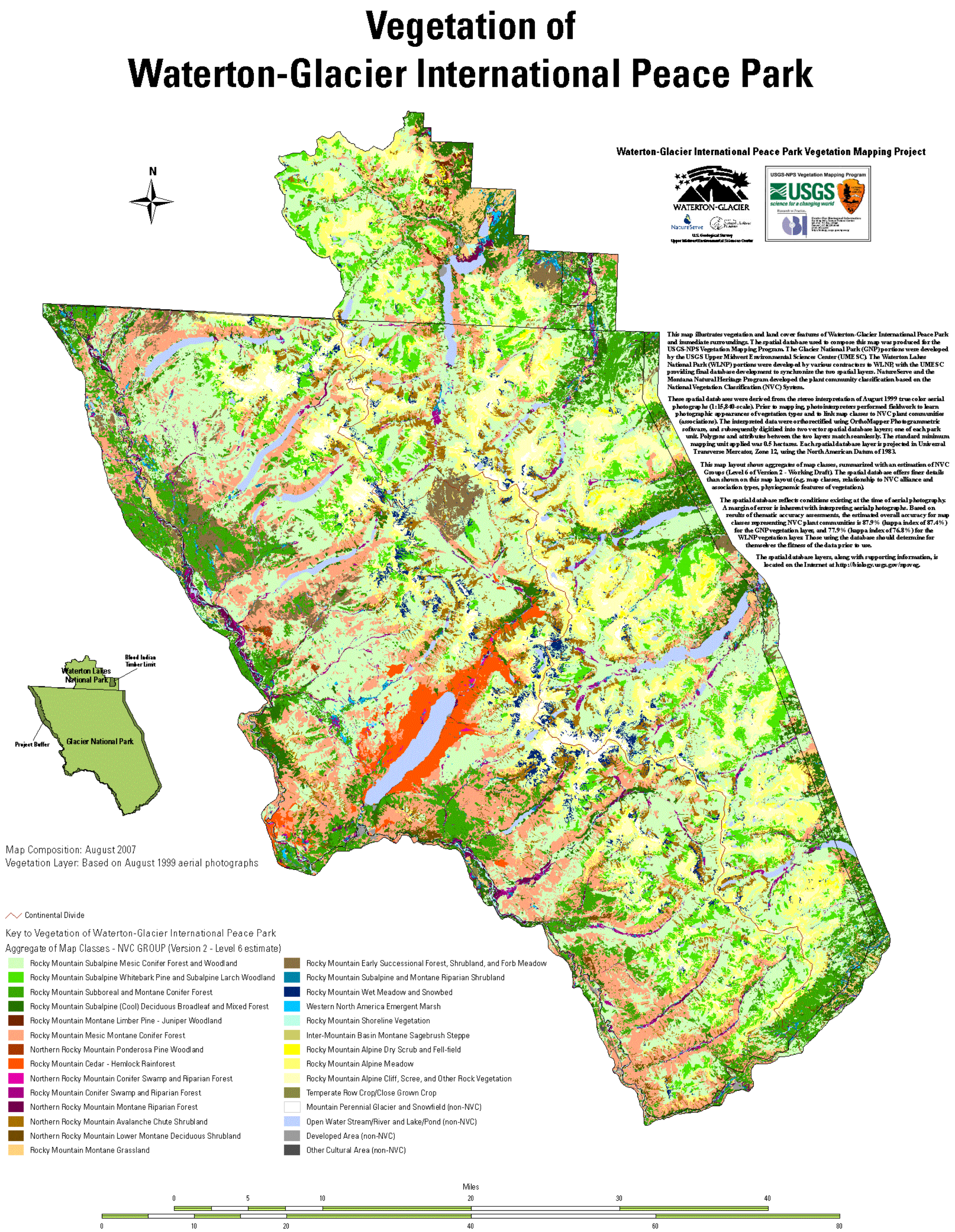

Figure 41. Map composition of the seamless Waterton-Glacier International Peace Park vegetation map coverage.

Discussion

We are pleased to have been able to produce vegetation spatial database layers of Waterton-Glacier IPP. Various skills and efforts from several individuals were utilized in order to accomplish the mapping element of this project. However, throughout the course of mapping the vegetation of Waterton-Glacier IPP, we encountered numerous challenges, ranging from those that were broad and conceptual, such as developing map classes to best reflect vegetation types, to those that were technical, such as the processing map data of high relief landscapes. Through these challenges, however, we have discovered new insights into mapping environments such as Waterton-Glacier IPP.

In order to expedite an anticipated lengthy project for Waterton-Glacier IPP, the mapping of vegetation types needed to begin prior to an established vegetation classification. Although communication between mappers and classifiers continued throughout the mapping process, classification estimates and theories provided less than solid footing to build strong mapping conventions. Speculation of vegetation types can be an equation for slower mapping, as the mapper is in a continual struggle to make concrete decisions from subjective concepts. By not having an established vegetation classification, not only can one's confidence in mapping decline, but the consistency in mapping can decline, too. It is reasonable to say that when mapping conventions are based on well-established vegetation classification data, the mapping process can become more efficient, and the map itself can become more reliable because it is based on concrete information from the start.

Similarly, the vegetation field key might benefit both map and classification if it were developed prior or at the onset of vegetation mapping. This would allow for the key to drive the map class development into truer alignment with the vegetation types, and at the same time, test the field key prior to its use for AA.

In contrast, we have seen first-hand through the mapping process of this project how the vegetation classification can develop into an even stronger classification. With the vegetation classification being somewhat flexible at the onset of mapping, this allowed for easier adjustments to be made as mappers and classifiers worked through classification concepts for mapping.

Another side benefit was that the mappers and classifiers spent many hours in workgroup settings to derive map classes and conventions in order to determine how best to map a developing vegetation classification. Even seemingly basic concepts, such as discerning forest and woodland types from each other, were not simple because of the diverse landscape setting of Waterton-Glacier IPP. Although working through theoretical classification concepts made for a slow start in our mapping efforts, these sessions provided exceptional opportunities for mappers and classifiers to learn and grow in each others' perspectives, which can be invested into future mapping efforts.

As for the relationship between map classes and vegetation types, it stands to reason that with parks having high diversity of vegetation types, few map classes can be developed to capture those vegetation types because of mere limitation in discerning them on aerial photographs. We found this to be true at Waterton-Glacier IPP largely because distinctions between vegetation types (typically shrub and herbaceous layers) are so fine that discerning them on aerial photographs is not practical. Either subtle changes in species composition within the herbaceous or shrub layers cannot be depicted with the human eye using the project's aerial photographs, or the layers were obstructed by other vegetation cover (e.g., tree canopy). To compound this, the more subtle the differences between vegetation types, the more difficult it is to determine what vegetation types should be aggregated together under a particular map class. A series of subtle changes in vegetation will eventually put us at opposite ends of the classification spectrum—obvious as each end might be, there is not an obvious placement in-between. This gives reason to the multiple numbers of vegetation types found within some of the map classes; e.g., nearly 25 vegetation associations represented by the Subalpine Fir - Engelmann Spruce Forest (FFS) map class.

In addition, a detailed vegetation classification, such as the one used for Waterton-Glacier IPP, promotes ambiguity between map classes, as vegetation types easily cross into more than one map class; e.g., the

Abies lasiocarpa - Picea engelmannii / Vaccinium scoparium / Xerophyllum tenax Forest association is represented by both the FFS and Subalpine Fir - Engelmann Spruce Woodland (WFS) map classes. Making distinct breaks, particularly subtle ones in complex vegetation patterns, is practically impossible. Nearly a 1:5 map class to plant association ratio was found at Waterton-Glacier IPP. This is an exact opposite to what is commonly dealt with further east in the United States where vegetation classification is rarely split by subtleties. For example, a 2:1 map class to vegetation community ratio resulted for the Effigy Mounds National Monument Vegetation Mapping Project. (Several phases of a map class representing plant communities were developed, depicting distinct and repetitive vegetation characteristics across the landscape and providing park resource managers additional information to make management decisions.)

It is important to consider, however, that with steep and diverse environmental gradients, complex fire history and large geographic area of the Waterton-Glacier IPP will result in a diverse assemblage of vegetation types. Given that the large areas of both parks are primarily forested, one would expect individual map classes of forest types, such as the Subalpine Fir - Engelmann Spruce Forest or Cedar - Hemlock Forest (mesic phase), to include a large number of associations. For example, spruce-fir forests and woodlands in the Waterton-Glacier IPP can span an elevational range of more than 1,000 m. Hence, the diversity of associations is quite high.

Specific to the WLNP mapping, one may conclude that there is an advantage in having the same person who collected vegetation plots—who also knows WLNP landscape and ecology well—also perform the photointerpretation mapping. At the same time, it can be deduced that the individual completing the WLNP mapping had several disadvantages. First of all, photointerpretation of vegetation was completed from print aerial photos instead of the transparency film; the prints are grainy with a loss of resolution in respect to the transparent film. Perhaps even a bigger disadvantage was that the WLNP mapper, despite all modes of communication that took place, was remote from the synergy of continual group discussion and decision making that occurred at the UMESC mapping lab. Furthermore, quality control from another experienced photointerpreter was not available for the WLNP photointerpreter to either check the work or provide feedback to the WLNP mapping.

As for the more technical aspects of mapping Waterton-Glacier IPP, dealing with both inherent angle distortions and scale changes within aerial photographs proved daunting. With these two variables coupled together, MMU templates are not foolproof as, from a bird's eye view, the true MMU size is distorted (either larger or smaller) the further away you get from the photo center, particularly of areas with high elevation changes. In addition, the scale varies within a photo from mountain top to valley bottom, making for adjustments not only with MMU application, but also with determining tree heights. As for employing OrthoMapper to orthorectify the interpreted overlays, the software performed well with the extreme landscapes of Waterton-Glacier IPP. However, even with the software doing its job, polygons were often stretched, pulled, squeezed, and even twisted apart from each other during the orthorectifying process. These squeezed or twisted apart polygons, which originally were near MMU size (from the photointerpreter's view of the aerial photo), become much smaller than MMU. The interpretation of these aerial photos post orthorectifying would have likely solved the majority of the above technical mapping issues, and should be considered for future parks.

Shadows cast from mountain sides also proved to be challenging for the photointerpreter. Total or near-total blackouts of the landscape increased mapping time. These blackout areas needed to be investigated to identify the map class(es) that existed there. This was completed by referring to adjacent sidelap photos or another set of aerial photos (e.g., the CIR set). Even though another aerial photo might "shed new light on the subject," the delineation mapping continued on the original aerial photo with the shadow cast, making for some interesting delineation experiences. Sometimes, the additional aerial photos did not provide better viewing of the area. Shadow casts on aerial photos over mountainous areas are always to be expected.

Accuracy Assessment

Methods

Purpose and Introduction

Our aim in mapping the vegetation of Waterton-Glacier International Peace Park (IPP) was to provide accurate locations of vegetation types as described by the National Vegetation Classification (NVC). A margin of error is inherent to interpreting vegetation using aerial photographs. Not only can thematic (map class) errors occur from the misinterpretation of an entire map polygon, but also by incorrectly delineating a portion of the polygon, where only part of the polygon is actually in error. Therefore, there are two types of errors we can assess from the vegetation map coverage: spatial error and thematic error. With this Accuracy Assessment section, we focus on thematic accuracy of the Waterton-Glacier IPP vegetation map coverages. From this point forward, the acronym "AA" refers to "thematic accuracy assessment."

Accuracy is a measure of how precise something is in regards to the true value. Accuracy can also be explained as a measure of the absence of errors—the more frequent the errors, the less the degree of accuracy. For this vegetation mapping project, AA is an analysis of data sets measuring the probability of map accuracy (or, the absence of error) with field classification acquired at randomly selected sites for each map class (thus, thematic accuracy assessment).

According to the Vegetation Mapping Program's (VMP) Accuracy Assessment Procedures document (TNC et al. 1994), AA of spatial data has three primary objectives: (1) to allow the users of the data to assess the data's suitability for a particular application, (2) to allow the producers of the data to learn more about the data's errors and improve the mapping process, and (3) to verify conformance to production standards. We focus here on the first two objectives, or views. These two views of an AA are "users' accuracy," which is the probability that the map actually represents what was found on the ground (also referred to as errors of commission), and "producers' accuracy," which is the probability that an AA point has been mapped correctly (also referred to as errors of omission). Both users' and producers' accuracy are obtained from the same set of data using different analyses.

Thematic error measures the discrepancy between the classification of the same X-Y coordinate on the map and in the field. The X-Y coordinate of the map is assigned the classification of the map polygon the coordinate rests in, whereas the X-Y coordinate of the field is assigned the classification determined by the surveyor. A thematic error results when the map classification does not equate with the observed classification in the field. A major assumption of AA is that the process of mapping and the process of assessment (e.g., the application of the classification system) are identical, thus a "false error" is not detected because of procedural differences. The challenge here is that the process of AA is based on field observance and the process of mapping is based on aerial photointerpretation.

We conducted AA of Glacier National Park (GNP) and Waterton Lakes National Park (WLNP) vegetation maps separately, since these two efforts were mapped by different mapping groups remote from each other and using slightly different equipment and methodology (e.g., aerial photo quality, ancillary data). The AA was performed only on map classes representing NVC natural/semi-natural vegetation types. Results of the AA are presented in contingency tables for each GNP and WLNP mapping efforts. (A contingency table is also referred to as an error matrix, confusion matrix, or misclassification matrix). The contingency tables are used to determine the degree of misclassification among classes. Accuracy requirements for the project specify 80% (the proportion of correctly assessed sites) accuracy for each map class (theme). A Kappa Index is also applied, which corrects for chance agreements in the contingency matrix.

Sampling Design

Glacier National Park

Ideally, AA is conducted after completion of a map project because the appropriate number of sites sampled is dependent on the area and number of polygons for each map class over the entire project area. There is purposeful intent within VMP standards to keep AA separate from mapping, as stated in the VMP's Accuracy Assessment Procedures (TNC et al. 1994), "Accuracy will be assessed at the conclusion of the mapping process for a specific park, and will therefore be independent of the mapping process."

For GNP, however, we conducted AA while mapping was still under way in order to meet project timelines and budget considerations. Our goal for the AA was to retain a strong scientific design in spite of the complications a three-year plan would entail. In addition, we needed to balance the strong scientific design with the logistical cost and time constraints of sampling one of the larger and more rugged parks. Thus, our strategy, guided by the standard protocols and methods described in the VMP's Accuracy Assessment Procedures manual (TNC et al. 1994) required these five steps: (1) allocating photointerpretation to the most accessible areas of GNP, (2) building a model to determine a target number of sample sites per map class and year, (3) allocating the sample sites using a stratified random design while controlling a variety of logistical and safety issues, (4) providing support and training to field crews, and (5) analyzing and reporting the results of the AA using contingency tables.

Photointerpretation and AA Coordination

The mapping effort was planned in anticipation of a three-year AA field effort, and thus, was prioritized by portions of GNP that were relatively accessible for AA field crews (Figure 42). We derived three major portions, or map phases; one for each of the three years. Each map phase was first interpreted and mapped (spatial coverage) before the sampling season began. Phase I mapping focused photointerpretation in areas of relatively easy access in the northeast portion of GNP. Areas selected for Phases II and III were based on a cost-surface analysis developed using ArcMap (Version 8.x, Environmental Systems Research Institute [ESRI], Redlands, California) by an in-house U.S. Geological Survey Upper Midwest Sciences Center geographic information system (GIS) analyst.

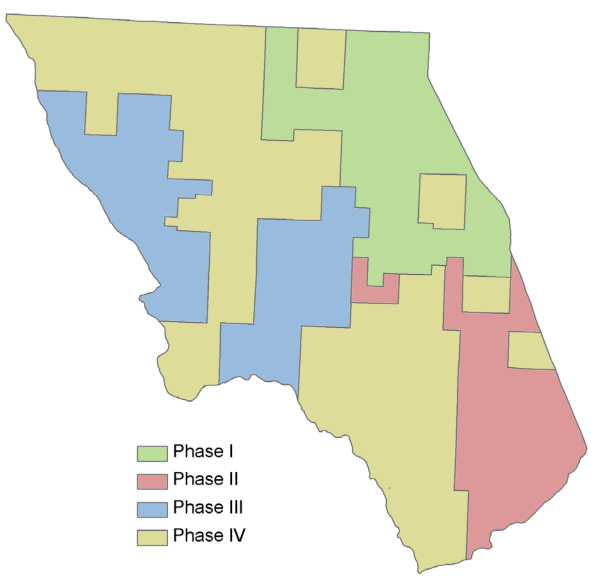

Figure 42. Areas of Glacier National Park prioritized for mapping that promote accessibility for accuracy assessment crews.

The cost-surface analysis modeled accessibility throughout GNP along a continuum from easy to extremely difficult. The development of the cost surface began by generating slope from a 30-m digital elevation model (DEM). Slopes >65% were considered absolute barriers, along with perennial streams and lakes. Targets used in the development of the cost-surface included trails, roads, campsites, and cabins. Areas where trails or roads crossed a perennial stream were considered passable. Final cumulative costs, which represented the shortest path with the least amount of cost, were stretched to values ranging from 0 to 100. Due to the difficult nature of accessing the higher values in this range, we focused the AA site generation on cumulative cost values <25 (Figure 43). Only in instances where map classes rarely occurred did we consider values >25.

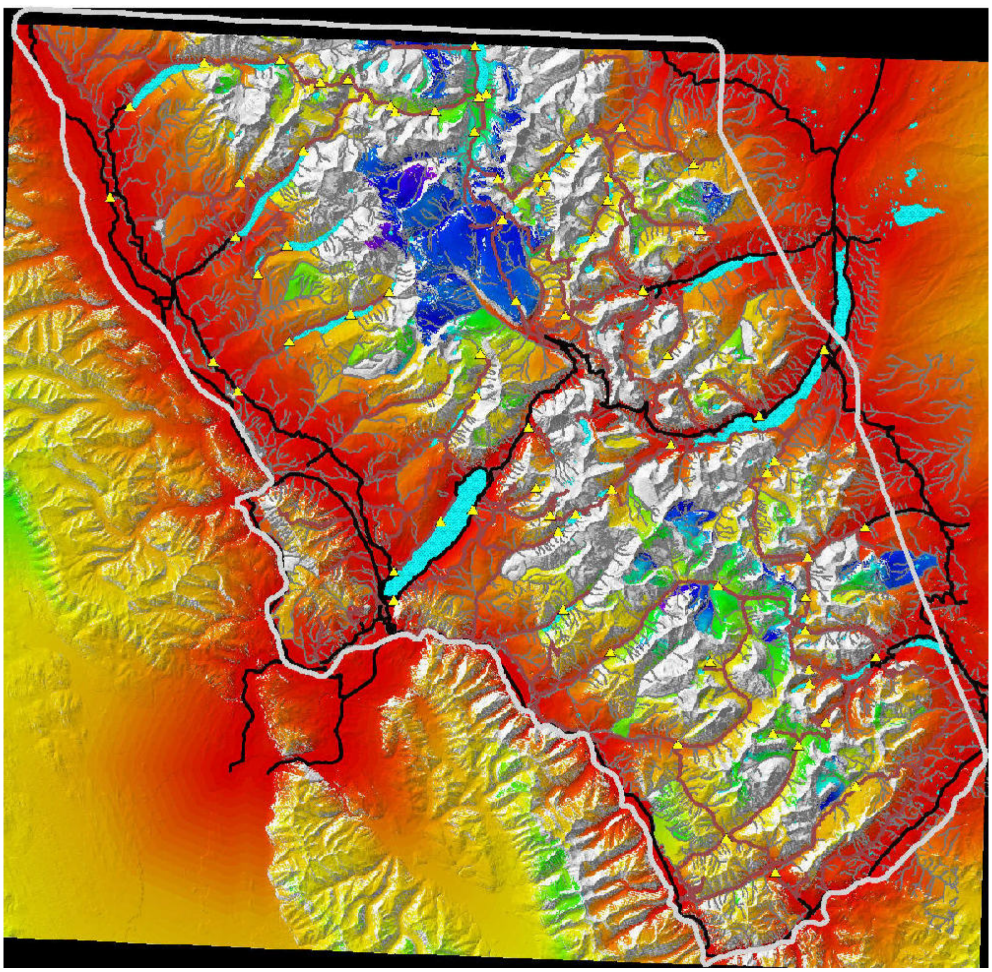

Figure 43. Cost-surface map of Glacier National Park to determine areas of accessibility for accuracy assessment crews.

Slopes >65% were considered absolute barriers, along with perennial streams and lakes. Targets used in the development of the cost-surface included trails, roads, campsites (yellow triangles), and cabins. Areas of yellow, orange, and red were considered low-cost and more accessible, whereas areas of green, blue, and purple were considered high-cost and less accessible. Areas of white were considered too high of cost for this accuracy assessment project, and thus deemed inaccessible.

Regions of difficult accessibility were mapped last (Phase IV) and were not included in the AA; the logistical costs to these areas would generally be too high. (In actuality, some areas of Phase IV were originally scheduled for Phase III mapping. Mapping Phase III, however, took longer than anticipated.

Phase III mapping was the onset of mapping areas west of the continental divided (CD), and new map classes and mapping protocols were introduced with an intrinsic learning curve.) The three phases selected for AA were generally divided between east and west of the CD, so that every map class would be sampled (Table 21).

Table 21. Mapping and accuracy assessment phases for Glacier National Park and environs.

Photointerpretation/Map	PHASE I	PHASE II	PHASE III	PHASE IV
Location	East of the CD	East of the CD	West of the CD	East and West of the CD
Mapping Year	2002–03	2003–04	2004–05	2005–06
Number of Photos	250	191	269	639
Percent of Project	19%	14%	20%	47%
AA Conducted	Yes	Yes	Yes	No
Points Sampled	290	339	299	n/a

Selecting Target Number of Sample Sites

Once we had developed the three-year plan for mapping and AA, we selected the sample sites based on the standard protocols and methods described in the VMP's Accuracy Assessment Procedures manual (TNC et al. 1994). The manual provides five scenarios for determining the number of sites using a weighting factor that allocates a larger number of samples to the abundant map classes and a smaller number of samples to the rarer map classes (Table 22). The scenarios present maximum and minimum sample sizes for a medium-size park that take into account statistical, as well as cost constraints and probable class abundance and frequency.

Table 22. Target number of accuracy assessment sample sites per map class based on number of polygons and area, with adjustments shown for Waterton-Glacier International Peace Park.

Scenario	Brief Scenario Description*	Frequency of Polygons/Map Class (Adj for WGIPP)	Area/Map Class (Adj for WGIPP)	Frequency of Samples/Map Class (Adj for WGIPP)
A	Abundant: many polygons covering a large area.	>30 (>300)	>50 ha (>500 ha)	30 (14/year over 3 years)
B	Relatively Abundant: few polygons covering a large area.	<30 (<300)	>50 ha (>500 ha)	20 (10/year over 3 years)
C	Relatively Rare: many polygons covering a small area (many polygons close to MMU).	>30 (>300)	<50 ha (<500 ha)	20 (10/year over 3 years)
D	Rare: few polygons covering a small area (may be widely distributed and most/all polygons close to MMU).	>5 and <30 (<300)	<50 ha (<500 ha)	5 (7/year over 3 years)
E	Very Rare: too few polygons covering a small area (most/all polygons close to the MMU).	<5 (<50)	<50 ha (<500 ha)	1 each polygon (2/year over 3 years)

*For complete scenario descriptions, see The Nature Conservancy et al. (1994).

The scenarios provided us initial guidelines for sample site allocation. However, instead of just one sampling strategy based on the scenarios, we needed three, one for each phase of mapping and field season. Equal distribution of the number of sites per year was desired for logistical reasons and to ensure sites for each map class were widely distributed. Furthermore, we needed to adjust the scenarios' recommended area and polygon frequency to account for the large size of GNP. To accomplish this task, we increased the area and polygon frequency for each scenario (Table 22). We also considered the number of sites that probably could be sampled during any given season. We did not want to give a higher target number than could be accomplished by the field crews. The assigned number of sites for each phase would eventually total the required number for statistical evaluation. If we had not made these adjustments, the majority of map classes would have each required at least 30 samples per year, exceeding the boundaries of time and financial constraints.

Before the adjusted formula was applied to each map phase, the map underwent modification for AA purposes. For all three map phases, a land ownership coverage (provided by GNP staff) was used to identify private lands within the project boundary. The private lands were erased from each map phase since field crews were unable to visit these locations. For Phase I and II maps, areas owned by the Blackfeet Indian Reservation were also erased. Lastly, due to extensive fires that occurred west of the CD post aerial photography, it was determined to erase areas of high burn severity from the Phase III map, but still focus AA efforts on areas of low burn severity. Burn severity maps representing 1999, 2000, 2001, and 2003 were supplied by GNP staff. Burn severity values existed in the attribute tables of each burn severity map (Table 23). It was determined that areas with low burn severity—those with values of 3 or 4—would remain part of the map used for AA site selection. All other burned areas were erased from the map.

Table 23. Burn severity values and their descriptions as depicted in the burn severity map attribute tables.

Burn Severity Value	Burn Severity Description
0	Extremes (e.g., snow)
1	High enhanced productivity
2	Low enhanced productivity
3	Unburned to very low burn severity
4	Low burn severity
5	Moderate to low burn severity
6	Moderate to high burn severity
7	High burn severity

Once the map for each phase was modified for areas accessible for field crews, area reports were exported from each map indicating the total area and the total polygon frequency represented by each map class. A target number of sampling sites was then determined for each map phase by applying the adjusted scenario design in Table 22.

Stratified Random Design

Once we determined the necessary number of sites needed for each map class, we loaded the information into a GIS program (designed by a GIS analyst at USGS UMESC) to randomly select sample sites by map class. The program contained a fixed set of decision rules to control logistical issues, deny access to dangerous locations, minimize ecotonal boundaries, and minimize potential geographic positioning system (GPS) errors. The GIS program captured these decision rules by first selecting all of the polygons within a map class. Areas of >65% slope were then erased within the map class polygons, as well as areas within a 10-m buffer around each polygon's edge. Next, the GIS program randomly selected a polygon within a map class as a target and then randomly selected the X-Y coordinate within the extent of that polygon. Once the site was selected, a 50-m buffer around the site was erased to eliminate the possibility of another site being selected within a minimum mapping unit (MMU) distance of the first site. Furthermore, the GIS program selected for a maximum of three sites in any one polygon. The GIS program continued to run until the number of sites needed was oversampled by four times. This oversampling allowed for the elimination of higher cost sites (those with a value >25), as well as additional sites for the field crews to visit if particular sites seemed inaccessible. In subsequent years, we used the same scenario model for Phases II and III, by first generating an area report to determine the number of sampling sites, and then using the GIS routine for the selection of sites.

Field crews were provided two versions of field maps showing sampling site locations for all three phases (years) of AA. One set of maps had background imagery consisting of 7.5-minute digital raster graphics (DRGs, 1:24,000-scale), and the other set of maps had background imagery consisting of 3.75-minute digital orthophoto quadrangles (DOQs, 1:12,000-scale) and/or aerial orthoimagery. The DOQs used for Phases I and II field seasons were USGS 1-m resolution black-and-white imagery based on 1990–91 National Aerial Photography Program (NAPP) photos mosaicked to full quadrangles and compressed (20x) into MrSIDs. The DOQ's used for the Phase III field season consisted of 1-m resolution true color (TC) orthoimagery from August 2004. This set of orthoimagery covered the entire Waterton-Glacier IPP with a 1-km buffer. Lastly, 0.33-m resolution TC orthoimagery from August 2002 was used for sites near paved roads or developed areas during all three phases of AA. The extent of this TC imagery buffers the road approximately 300 m in length.

In addition to the background imagery, other data sets plotted on the maps included AA site locations, biophysical units (BPUs) from the gradsect (gradient-oriented transect) analysis (Phase I only; gradsect originally developed for the vegetation sampling strategy), polygon boundaries of the vegetation map, trails, roads, and buildings (when useful for navigation). The AA site number was always labeled on the field maps. The maps were produced at scales ranging from 1:4,000 to 1:24,000, depending on how tightly clustered the AA sites were. The finer scaled maps were produced for areas where several sites were clustered together to help with labeling and to help the field crews get a better map visual of the site location. In addition, field crews were provided with hardcopy X-Y coordinates for AA site locations during the Phase I field season. For Phases II and III field seasons, the X-Y coordinates were digitally uploaded to the field crew's Garmin GPS units using the DNRGarmin GPS Application software (Minnesota Department of Natural Resources). All data were managed in the Universal Transverse Mercator (UTM) projection, Zone 12, using North American Datum of 1983 (NAD 83).

Waterton Lakes National Park

The AA site selection process of WLNP employed essentially the same methodology as Phases II and III of GNP. However, we applied the AA site selection program to only the western two-thirds of the WLNP map because the eastern third of the map displayed significant geospatial displacement needing to be resolved before we could subject it to a stratified site selection. Although this displacement was corrected, it was not completed in time for the 2005 AA site selection. As with GNP, we derived a cost-surface map for WLNP using similar data layers, however, a 100-m resolution DEM provided to us from Canada was used instead of the 30-m resolution DEM we used for GNP.

Field Data Collection

Maps created for the AA portion of the project were used to select a number of sites clustered in an area to be visited during the field day. Also, the AA site coordinates were loaded into GPS units before field work began. Topographical maps, DOQ imagery, and Garmin GPS units were then used for navigation and for recording coordinates at the field site.

Once site coordinates were reached, the AA field crew determined how and where to set up the AA observation plot within the MMU area. The field crew determined what vegetation community appeared to be the most prominent community by traversing the MMU area. If only one community was present, the observation plot was placed in a representative area of that community. If more than one community appeared to be present, the team decided what community covered the largest area within the MMU.

Occasionally, polygons were encountered smaller than the MMU. During the mapping process, we tended to map distinctive scenarios of vegetation types somewhat below the MMU to capture the unique change in the landscape (e.g., a small wetland in the midst of a large forest stand). Also, the inclination during photointerpretation was to map below the MMU to account for angle distortions and scale changes from extreme elevation changes, both inherent to the aerial photos. In these instances, where polygons are smaller than the MMU, the plot size and shape was adjusted by the field crew to fit within the polygon and reflect the dominant vegetation community present.

After the placement of a plot had been determined, a 400 m^2 circular plot (11.28 m radius) or square plot (20 m x 20 m) was measured. The plot edges were marked with flagging. Ecotonal or heterogeneous areas were avoided whenever possible.

The UTM coordinates were recorded at the center of the established observation plot sampling area and not at the original X-Y coordinate navigated to. The field crew waited until the Estimated Position Error (EPE) on the GPS was <9 m before recording the new field coordinates. The Dilution of Precision (DOP, a measure of satellite geometry quality) was also recorded. The required datum, NAD83, was rechecked on a regular basis.

The representativeness of the AA observation plot to the rest of the MMU was recorded, and if possible, to the entire polygon (although the AA field team was not always able to assess the entire polygon, especially the larger ones). This information was useful during the analyses to determine whether or not the site was an "inclusion" to the MMU or polygon and also how heterogeneous the MMU and polygon were.

The following physical characteristics were recorded:

- Location (e.g., Cracker Lake, Sunrift Gorge, Upper Belly River);
- Slope (%);
- Aspect (aspect of drainage, in degrees);
- Elevation (from topographic maps);
- Cowardin classification (upland, riverine, palustrine, or lacustrine);
- Landform (a list was provided);
- Topographic position (a list was provided); and
- Surficial geology (a list was provided, or a surficial geology coverage was consulted and added during data entry).

A digital photo of the area was taken with the AA observation plot number written on a slate and included within the picture view. Photos were taken at an angle best representing the character of the vegetation within the observation plot. The photo number was recorded on the data sheet.

The following structural information was recorded:

- Percent coniferous:deciduous—defined as the percentage ratio of coniferous trees to deciduous trees in the canopy layer only; this is an important number for determining what key to use (e.g., coniferous, mixed, or deciduous stands); and
- Percent cover and dominant species of each strata—defined as the percent cover (Table 24) represented by each of the height classes (Table 25) in the AA observation plot, reflecting the actual height of vegetation, rather than potential height (as in young or browsed trees or shrubs); height classes included both trees and shrubs (deciduous and coniferous) present in each strata.

Table 24. Strata and cover classes used in collecting accuracy assessment observation plot data.

Strata Classes		Cover Classes	
Strata	**Range**	**Code**	**Range**
Emergent trees	Emergent over canopy	T	<1%
Canopy	Main canopy of trees	P	1–5%
Subcanopy	<10 cm dbh	1	5–10%
Tall woody	2–5 m tall	2	10–15%
Medium woody	0.5–2 m tall	3	15–25%
Short woody	<0.5 m tall (included all shrubs of this height)	4	25–50%
Herbaceous	(% cover of non-woody vegetation)	5	50–75%
		6	75–100%

Table 25. Height and maturity classes used in collecting accuracy assessment observation plot data.

Height Classes		Maturity Classes for Trees	
Code	**Range**	**Code**	**Range**
1	<0.5 m	SD (seedling)	<1 m tall
2	0.5–1 m	SA (sapling)	>1 m tall, 5" dbh
3	1–2 m	P (pole)	5–9" dbh
4	2–5 m	M (mature)	9–21" dbh
5	5–10 m	OM (overmature)	>21" dbh
6	10–15 m		
7	15–20 m		
8	20–35 m		
9	35–50 m		
10	>50 m		

The presence and abundance (Table 24) of indicator species within the AA observation plot was also determined by carefully walking through the plot area and recording the presence and percent cover (expressed in cover classes) of all indicator species present. Indicator species lists were generated by the ecology team before the AA field season began.

Once a vegetation community was determined with the field keys, the community description was read to affirm the initial field call. The vegetation code for the community was subsequently recorded as the primary code. An alternative vegetation type was recorded if the vegetation community was a close fit between two community types. If present, other vegetation types within the MMU were also recorded even though they may be inclusions. If another community seemed to share dominance within the MMU, it was recorded under "Other veg types within MMU."

Comments regarding the AA observation plot were also recorded, which documented anything relevant in describing the observation plot or MMU. If pertinent, the following specific comments were recorded:

- Classification Comments—such as how well the AA observation plot keyed, and if not well, reasons why;
- Environmental—such as relevant attributes of the physical setting not represented by the categorical fields; e.g., if the aspect of the MMU is variable, yet the plot only reflects one aspect (therefore, may explain why there is more than one vegetation type in the MMU), or if there has been extensive disturbance in the area (fire, grazing, trail construction, etc.);
- Landscape—any other important components of the physical setting not fitting into the other categories; and
- Animal Use/Disturbance—such as extensive grazing or browsing that alters the appearance or skews the plant composition.

The AA field data form used to complete this process is presented in Appendix K: Accuracy Assessment Observation Plot Field Form.

The data recorded on the AA field data forms were then entered into the PLOTS Database System by the field crews, with successive quality control measures. The AA observation plot data sheets were also reviewed in regards to classification of the site.

Data Analyses

Initial Comparison

The AA observation plots were imported into ArcView GIS (Version 3.3, ESRI, Redlands, California) where we performed a spatial join of the observation data with the map polygon data. A crosswalk table providing the necessary linkages between the map classes and the vegetation types was also imported into ArcView. Here, the two tables were joined resulting in each vegetation type being linked to the map class(es) it occurred in. This allowed us to compare each AA field call to the corresponding map class code(s). Finally, we exported the data out of ArcView and into a spreadsheet format, where we compared and tabulated the AA field calls to the map polygon calls. Our comparison accepted the primary and alternative field calls as correct if they corresponded with the same map polygon call.

Our initial comparison revealed an overall accuracy well below VMP standards, for both the GNP and WLNP layers. From experience with other AA projects, we suspected many of these mismatches to be “false” errors. We define a false error as a mismatch between the map polygon classification and the AA observation classification if any of the following are evident: (1) an error in GPS field coordinates, (2) a missing or misapplied field call, (3) the field site assessment area was smaller than the polygon MMU, or (4) a map automation error was evident. To identify and correct false errors, we subsequently reviewed all mismatches. This review process involved using ArcMap (Version 9.1, ESRI, Redlands, California) to pinpoint the location of each AA observation site within the corresponding polygon and then looking at each AA site location and its polygon on the aerial photographs using a Topcon (MS-3) mirror stereoscope. At the same time, we also reviewed the AA plot data sheet to gain fuller insight of the ground data. From this process, we were able to assess most of the disagreement, resulting in either a match or a true error using the procedures that follow.

Spatial GPS Coordinate Error

A spatial coordinate error occurred when the GPS acquired inaccurate field coordinates, causing a site to fall within an adjacent polygon on the map coverage. Through our sampling design of selecting sites >10 m from polygon edges, we were able to minimize these errors. For sites we determined having spatial GPS field coordinate displacement, we adjusted accordingly for the analysis to reflect the intended polygon’s map class, whenever possible.

Map Automation Error

A map automation error was caused by a spatial shift in the polygon data, sending the AA team to a site that perhaps in reality is outside of the area the polygon was originally intended for. This was predominately a problem in the WLNP layer.

Unclassified Vegetation Type on Field Data Sheet

Field data having no classification assignment surfaced as errors on our initial analysis. Many of these unassigned types were difficult, or even impossible to link to a particular association because they were disturbed or ecotonal sites. We classified these data when possible, sometimes to the NVC alliance level, and sometimes, we derived unique category types (park specials).

Incomplete Crosswalk between Map Classes and Vegetation Types

The AA process revealed additional vegetation types initially missed in the earlier versions of the crosswalk between map classes and vegetation types. We added these vegetation types appropriately to the developing crosswalk, and subsequently reapplied the crosswalk to the mapped polygons to determine matches or true errors.

Questionable Field Call

Sometimes the correctness of the field classification came into question as we reviewed the field data. Although alternative field calls often resolved the matter, occasionally a field call was better qualified as another vegetation type. These errors were usually due to discrepancies between the actual cover values and what the stand was called by the field crews.

An Inclusion

An inclusion would occur when the assessed area of the observation plot was below the MMU used for mapping. We discovered instances where, after reviewing the interpreted data and aerial photographs, the plots were an inclusion to the surrounding map class. Although inclusions were not always discernable, certain vegetative features can be quite apparent from each other on the aerial photographs (e.g., woodland with exposed rocky outcrop vs. open forest with dense tall shrub layer), allowing easy assessment under the stereoscope of site inclusions. In these instances, the polygon call was given the benefit if the photo signature met mapping conventions.

Inclusions are a common problem regardless of plot size during AA. For Waterton-Glacier IPP, it was particularly problematic because the AA plot size was smaller than the MMU (see previously discussed methods regarding field data collection for AA).

Final Comparison

Glacier National Park and Environs

Of the 918 AA observation plots originally collected (Figure 44), we dropped 36 sites from the GNP map analyses. The majority of the dropped sites (n = 29) were of two map classes: Mixed Regenerate Shrubland (SMR) and Mixed Conifer Regenerate Forest (FCR). (These two map classes represented disturbed communities.) Other sites (n = 2), representing the Lodgepole Pine Wet Forest (FPW) map class, were dropped because this map class was added too late in the mapping process for proper AA consideration. The remaining sites (n = 5) were dropped due to unresolved GPS errors. We used the remaining 882 sites for the final comparison analysis.

Waterton Lakes National Park and Environs

Of the 242 AA observation plots originally collected (Figure 44), we dropped only two sites from the WLNP map analyses. One site was of the SMR map class, and the other was due to an unresolved GPS error. We used the remaining 240 sites for the final comparison analysis.

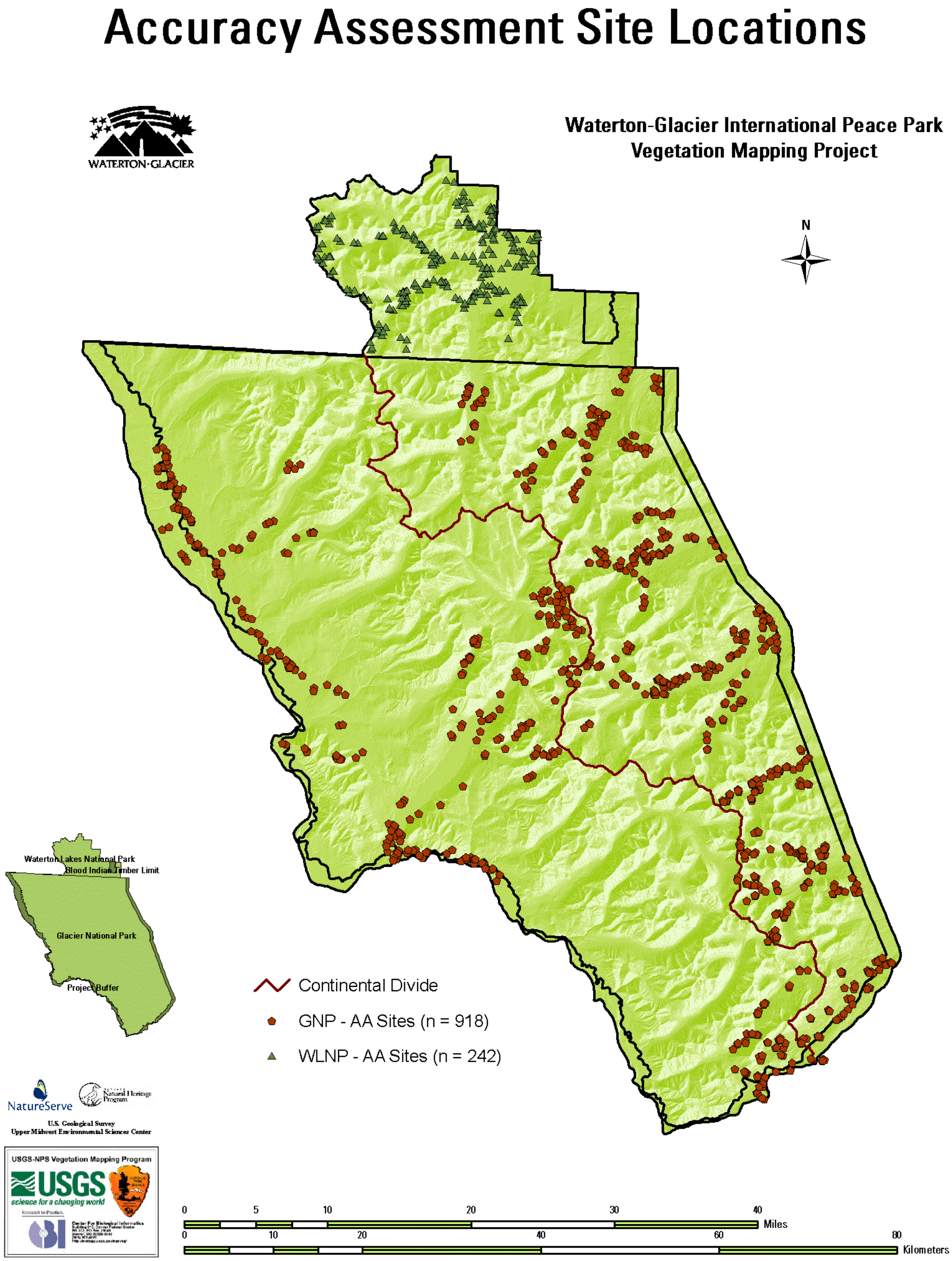

Figure 44. Locations of accuracy assessment sites for validating the Waterton-Glacier International Peace Park vegetation maps.

Contingency Tables

After performing the same analyses methods to both the GNP and WLNP map coverages, we transferred the results of each study into their own contingency table (matrix) where we calculated users' and producers' accuracy percentages for each map class. The matrix shows both the frequency of agreement and placement of disagreements. In deriving these tables, it should be noted that the GNP contingency table does not include the Bearberry Dwarf-shrubland (DBB) map class because this map class does not exist in the GNP map coverage; the DBB map class is included in the WLNP table. In turn, the WLNP contingency table lacks five map classes; (1) Western Larch Forest (FWL), (2) Ponderosa Pine Woodland (WPP), (3) Cedar - Hemlock Forest (mesic phase) (FCH), (4) Cedar - Hemlock Forest (wet phase) (FCS), and (5) Sagebrush - Fescue Shrub Herbaceous (HSS). No occurrences of these map classes exist in the WLNP map coverage; they are included in the GNP table.

In addition, the Krummholz Shrubland (SFK) map class was officially derived post mapping. Therefore, this theme did not receive its own random selection of AA sites, and it could not be treated independently in the AA analyses, but rather folded into the Subalpine Fir - Engelmann Spruce Woodland (WFS) map class. Also, due to the short height of these tree species, it was often too difficult to discern between tree types on the aerial photos. Therefore, SFK represents krummholz versions of WFS, Whitebark Pine Woodland (WWB), Subalpine Larch Woodland (WSL), Limber Pine Woodland (WLM), and on rarity, Douglas-fir Woodland (WDF), and this was taken into account during the analyses.

Results

The AA contingency tables are presented in Tables 26 and 27. (Appendix L: Accuracy Assessment Contingency Tables provide higher quality versions in electronic spreadsheet format.) They show the accuracy of each map class along with the 90% confidence interval, with users' accuracy reflecting errors of inclusion (commission errors) and producers' accuracy reflecting errors of exclusion (omission errors). The width of each confidence interval is reflected by the number of samples; the greater number of samples results in narrower confidence intervals, and vice versa.

Although it is not easy to categorize true errors, errors of commission and omission are generally caused by interpretative errors due to a polygon being incorrectly classified or delineated. Particularly with mislaid polygon boundaries, it goes to reason that an entire polygon may not necessarily be incorrect, as only a small area within the polygon was tested in the field and determined not to agree with the classification of the entire polygon; other locations within the polygon might actually agree with the assigned map class when tested in the field. Likewise, an entire polygon may not be necessarily correct, even though it may be in agreement at a particular AA site location; other locations within the polygon might actually disagree with the assigned map class when tested in the field. Therefore, the AA results are a gauge to gain a greater understanding in the usefulness of the map for one's particular application.

In the pages following the AA contingency tables, we discuss those map classes having lower accuracies (with some having broad confidence intervals) to provide some explanation to both users and producers. Those map classes having low accuracies indicate either problems with the photointerpretation mapping or disparities between the vegetation classification and map classification. In cases of errors to producers' accuracy (omission errors), we hope other producers also consider ways to circumvent similar problems in the future. In cases of users' accuracy (commission errors), we hope users are able to determine the fitness of the data for their specific needs.

In these discussions, "RD" refers to relative density.

Table 26. Contingency table showing accuracy assessment results of the Glacier National Park (and environs) vegetation map coverage.

		FIELD SAMPLES - REFERENCE DATA																																	COMISSION			
	MAP CODES	FLP	FDF	FFS	FSP	FSW	FWL	FAP	FCW	FEP	FWM	FCH/ FCS	WLP	WLM	WWB	WDF	WFS	WSL	WPP	SAD	SDS	SWL	SAM	DWD	HGL	HSS	HES	HWM	HSF	HPF	VCT	VSL/ VEE	CSA	CSW	TOTAL	USERS' ACCUR-ACY	90% Confidence Intervals -	90% Confidence Intervals +
MAP DATA - PREDICTION DATA	FLP	37		1			1																												39	95%	88%	102%
	FDF	2	30	4			1												1																38	79%	67%	91%
	FFS	2	2	38			1																												43	88%	79%	98%
	FSP			5	21																	1													27	78%	63%	93%
	FSW					24																													24	100%	98%	102%
	FWL	1	3	2			19																												25	76%	60%	92%
	FAP							32		2										1		1													36	89%	79%	99%
	FCW							1	28																										29	97%	89%	104%
	FEP	1		1	1				1	40		1										1													46	87%	78%	96%
	FWM				2					1	25	1																							29	86%	74%	98%
	FCH/FCS		1							1		15																							17	88%	72%	104%
	WLP												22			1																			23	96%	86%	105%
	WLM			1									1	9																					11	82%	58%	105%
	WWB	1	1	1									1	3	19		1																		27	70%	54%	87%
	WDF		1							1		1	2	3		24	1																		33	73%	58%	87%
	WFS		1	2										1	2	3	30			1													1		41	73%	61%	86%
	WSL																	11																	11	100%	95%	105%
	WPP																		8																8	100%	94%	106%
	SAD																			39			1											1	41	95%	88%	102%
	SDS																				27												1	1	29	93%	84%	103%
	SWL								4													31					1							1	37	84%	72%	95%
	SAM	1		2																2			29												34	85%	74%	97%
	DWD																							24									2		26	92%	82%	103%
	HGL																				1				32										33	97%	91%	103%
	HSS																								1	6									7	86%	57%	115%
	HES																					1					19								20	95%	84%	106%
	HWM																						2			1		20	1						24	83%	69%	98%
	HSF																												6						6	100%	92%	108%
	HPF																													3					3	100%	83%	117%
	VCT																														25				25	100%	98%	102%
	VSL/VEE																											1				22			23	96%	86%	105%
	CSA																									1							32	2	35	91%	82%	101%
	CSW																			1	1							2						28	32	88%	76%	99%
OMISSION	Total	45	39	57	24	24	22	33	33	45	25	18	26	16	21	28	32	11	9	44	29	35	32	24	33	8	20	23	7	3	25	22	36	33	882			
	PRODUCERS' ACCURACY	82%	77%	67%	88%	100%	86%	97%	85%	89%	100%	83%	85%	56%	90%	86%	94%	100%	89%	89%	93%	89%	91%	100%	97%	75%	95%	87%	86%	100%	100%	100%	89%	85%				
	90% Confidence Interval -	72%	65%	56%	74%	98%	72%	91%	73%	80%	98%	66%	71%	33%	78%	73%	85%	95%	66%	80%	84%	78%	81%	98%	91%	44%	84%	73%	57%	83%	98%	98%	79%	73%	Total Samples = 882			
	90% Confidence Interval +	93%	89%	78%	101%	102%	101%	103%	97%	98%	102%	101%	98%	80%	103%	98%	102%	105%	112%	98%	103%	99%	101%	102%	103%	106%	106%	101%	115%	117%	102%	102%	99%	97%	Total Correct = 775			

OVERALL ACCURACY = 87.9% KAPPA INDEX = 87.4% KAPPA INDEX LOWER 90% CONFIDENCE LEVEL = 85.6% KAPPA INDEX UPPER 90% CONFIDENCE LEVEL = 89.3%

*Map classes SAM and SDS each had one error to map class SMR. SMR was not assessed for accuracy and thus, is not shown in this matrix.

*Map classes FLP and FSP each had one error to map class FPW. FPW was not assessed for accuracy and thus, is not shown in this matrix.

Table 27. Contingency table showing accuracy assessment results of the Waterton Lakes National Park (and environs) vegetation map coverage.

		FIELD SAMPLES - REFERENCE DATA																														COMISSION			
	MAP CODES	FLP	FDF	FFS	FSP	FSW	FAP	FCW	FEP	FWM	WLP	WLM	WWB	WDF	WFS	WSL	SAD	SDS	SWL	SAM	DBB	DWD	HGL	HES	HWM	HSF	HPF	VCT	VSL/ VEE	CSA	CSW	TOTAL	USERS' ACCUR-ACY	90% Confidence Intervals -	90% Confidence Intervals +
MAP DATA - PREDICTION DATA	FLP	12		2																												14	86%	67%	105%
	FDF	1	4	2	1		1		1					1																		11	36%	8%	65%
	FFS	1		12											1								1									15	80%	60%	100%
	FSP				2				4																							6	33%	-7%	73%
	FSW			1		2																										3	67%	5%	128%
	FAP						12											1														13	92%	76%	108%
	FCW							6																								6	100%	92%	108%
	FEP								14									1														15	93%	79%	107%
	FWM								1	1																						2	50%	-33%	133%
	WLP										2																					2	100%	75%	125%
	WLM											8		2																		10	80%	54%	106%
	WWB												7		2	1																10	70%	41%	99%
	WDF			1			1		3		2			6																		13	46%	20%	73%
	WFS														5					1												6	83%	50%	117%
	WSL			1												7				1												9	78%	49%	106%
	SAD																3															3	100%	83%	117%
	SDS						1											9					1									11	82%	58%	105%
	SWL						1	1											9													11	82%	58%	105%
	SAM																1			3												4	75%	27%	123%
	DBB																				2											2	100%	75%	125%
	DWD																				1	0								1		2	0%	-25%	25%
	HGL																	2					16									18	89%	74%	104%
	HES																		1				1	2	1							5	40%	-6%	86%
	HWM																								6							6	100%	92%	108%
	HSF																									2						2	100%	75%	125%
	HPF																										1					1	100%	50%	150%
	VCT																											6				6	100%	92%	108%
	VSL/VEE																												6			6	100%	92%	108%
	CSA																			2										11		13	85%	64%	105%
	CSW																1						1								4	6	67%	27%	107%
OMISSION	Total	14	4	19	3	2	16	7	23	1	4	8	7	9	8	8	5	13	10	7	3	0	20	2	7	2	1	6	6	12	4	231			
	PRODUCERS' ACCURACY	86%	100%	63%	67%	100%	75%	86%	61%	100%	50%	100%	100%	67%	63%	88%	60%	69%	90%	43%	67%	0%	80%	100%	86%	100%	100%	100%	100%	92%	100%				
	90% Confidence Interval -	67%	88%	42%	5%	75%	54%	57%	42%	50%	-4%	94%	93%	35%	28%	62%	14%	44%	69%	5%	5%	0%	63%	75%	57%	75%	50%	92%	92%	74%	88%	Total Samples = 231			
	90% Confidence Interval +	105%	113%	84%	128%	125%	96%	115%	80%	150%	104%	106%	107%	98%	97%	113%	106%	94%	111%	81%	128%	0%	97%	125%	115%	125%	150%	108%	108%	109%	113%	Total Correct = 180			

OVERALL ACCURACY = 77.9% KAPPA INDEX = 76.8% KAPPA INDEX LOWER 90% CONFIDENCE LEVEL = 72.0% KAPPA INDEX UPPER 90% CONFIDENCE LEVEL = 81.6%

Accuracy Results: Glacier National Park and Environs Map Coverage

The AA results revealed an overall accuracy of 87.4%, which includes kappa adjustments for chance agreements (90% confidence interval of 85.6–89.3%, n = 882), well above the VMP accuracy standard of 80%. Individual map class accuracies also meet the 80% accuracy standard with few exceptions.

Concentrations of commission errors (users' accuracy) are primarily of Subalpine Fir - Engelmann Spruce Forest (FFS), Subalpine Fir - Engelmann Spruce Woodland (WFS), Whitebark Pine Woodland (WWB), Douglas-fir Forest (FDF), Douglas-fir Woodland (WDF), Western Larch Forest (FWL), and Engelmann Spruce Forest (FSP). Concentrations of omission errors (producers' accuracy) are chiefly of FFS, Limber Pine Woodland (WLM), and FDF. Below, we summarize those map classes having lower users' and/or producers' accuracies for the GNP and environs map coverage.

Subalpine Fir - Engelmann Spruce Forest (FFS) Map Class

The users' accuracy (88%, n = 43) for the Subalpine Fir - Engelmann Spruce (FFS) map class is above accuracy standard, but the producers' accuracy is below standard with the uppermost confidence interval nearing the standard (67% with a 90% confidence interval of 56–78%, n = 57).

Producers' Accuracy of FFS

Of the 57 AA sites classified by the AA field crews as vegetation types represented by the FFS map class, 19 were mapped with a map class other than the FFS map class.

Five of these 19 AA sites were mapped with the Engelmann Spruce Forest (FSP) map class, largely because mapping conventions were developed and applied long before a crosswalk to vegetation types was fully understood. (This, in turn, has also lowered the producers' accuracy for FSP, as discussed further below.) The FSP map class was distinguished from the FFS map class based on two primary features: (1) spruce dominated the canopy and (2) the location was riparian. Some vegetation types, however, represented by the FFS map class occupy a wide variety of topographical sites—including riparian—and have variable canopy compositions. We learned this variability early on in the project, yet we made a decision to continue with the original mapping convention realizing some polygons mapped as FSP might contain vegetation types of FFS. The alternative was to map FSP more conservative. This, however, would probably result in more errors of omission for the FSP map class.

Four other AA sites were mapped with the Douglas-fir Forest (FDF) map class, due to differences in estimating the RD between conifer species. These instances were interpreted during mapping as >25% RD of Douglas-fir and <25% RD of subalpine fir. The AA field team found the converse to be true, resulting in the errors.

Two more AA sites were mapped with the Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial (SAM) map class. This could be due to either forest growth from the date of photography to AA field date (up to six years apart), or divergence of conventions between the vegetation and map classifications.

Other errors in producers' accuracy for FFS are depicted as follows: discernment between forest and woodland characteristics (two errors to Subalpine Fir - Engelmann Spruce Woodland, WFS), a disagreement about the presence of whitebark pine (one error to Whitebark Pine Woodland, WWB), a disagreement about the presence of limber pine (one error to Limber Pine Woodland, WLM), a polygon drawn incorrectly (one error to Lodgepole Pine Forest, FLP), a disagreement in the RD of deciduous trees (one error to Mixed Conifer - Deciduous Forest, FEP), and mapping vegetation types at a lower density than the vegetation description allowed (two errors to Western Larch Forest, FWL).

Subalpine fir - Engelmann Spruce Woodland (WFS) Map Class

The producers' accuracy (94%, n = 32) for the Subalpine Fir - Engelmann Spruce Woodland (WFS) map class is well above accuracy standard, but the users' accuracy is low with the upper range of the confidence interval exceeding the standard (73% with a 90% confidence interval of 61–86%, n = 41).

Users' Accuracy of WFS

Of the 41 AA sites located in polygons classified as WFS, 11 were classified by the AA field crews as vegetation types represented by map classes other than the WFS map class.

Three of these 11 AA sites were classified as vegetation types belonging to the Douglas-fir Woodland (WDF) map class. Another AA site was classified as a vegetation type belonging to the Douglas-fir Forest (FDF) map class. We suspect during photointerpretation the RD between conifer species was either misinterpreted or not distinguishable within the tree canopy.

Two AA sites were classified as vegetation types belonging to the Whitebark Pine Woodland (WWB) map class. The RD of whitebark pine trees was misinterpreted as too low, thus giving credence to using the WFS map class. Another AA site was classified as a vegetation type belonging to the Limber Pine Woodland (WLM) map class, again a stand where the pine was not apparent on the aerial photograph.

Two more AA sites were classified as vegetation types belonging to the Subalpine Fir - Engelmann Spruce Forest (FFS) map class. For both cases, the primary tree species are in agreement, however, the forest vs. woodland characteristics are not.

Two other AA sites were classified as vegetation types belonging to the Deciduous Shrubland: Avalanche/Snow Burial (SAD) map class and the Dwarf-shrub/Herbaceous Complex: Dry - Mesic (CSA) map class.

Whitebark Pine Woodland (WWB) Map Class

The producers' accuracy (90%, n = 21) for the Whitebark Pine Woodland (WWB) map class is well above accuracy standard, but the users' accuracy is low with the upper range of the confidence interval exceeding the standard (70% with a 90% confidence interval of 54–87%, n = 27).

Some of this is due to our mapping conventions, which gave precedence to lesser amounts of whitebark pine than the vegetation descriptions themselves allow for those types belonging to WWB. This more aggressive approach to mapping WWB was in response to the heightened awareness of whitebark pine research and management at Waterton-Glacier IPP.

Users' Accuracy of WWB

Of the 27 AA sites located in polygons classified as WWB, 8 were classified by the AA field crews as vegetation types represented by map classes other than the WWB map class.

Three of these eight AA sites were classified as vegetation types belonging to the Limber Pine Woodland (WLM) map class. The effort to map the vegetation types of WWB and those of WLM separate from each other was challenging; not only were the signatures on the aerial photographs quite similar, some associations of WLM occurred at higher elevations than we expected, occurring within an elevation zone considered exclusively whitebark pine territory. Our confidence in mapping WLM was relatively high when on dry, rocky slopes with west and southwest aspects in the upper montane. However, when WLM occurred on higher elevations or on different aspects, our confidence in mapping between whitebark pine and limber pine became lower.

Two other AA sites were classified as vegetation types belonging to the Subalpine Fir - Engelmann Spruce Forest (FFS) and Subalpine Fir - Engelmann Spruce Woodland (WFS) map classes. These disagreements were largely due to the AA field crews finding little, and sometimes, no whitebark pine within their observation plots.

One AA site was classified as a vegetation type belonging to the Douglas-Fir Forest (FDF) map class, with limber pine present as a minor component. Two more AA sites were classified as vegetation types belonging to the Lodgepole Pine Forest (FLP) and Lodgepole Pine Woodland (WLP) map classes.

Limber Pine Woodland (WLM) Map Class

The users' accuracy (82%, n = 11) for the Limber Pine Woodland (WLM) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval just reaching the standard (56% with a 90% confidence interval of 33–80%, n = 16).

Producers' Accuracy of WLM

Of the 16 AA sites classified by the AA field crews as vegetation types representative of the WLM map class, 7 were mapped with a map class other than the WLM map class. These errors, coupled with relatively few AA samples, resulted in the broad 90% confidence interval for the producers' accuracy (33–80%).

Three of these seven AA sites were mapped with the Whitebark Pine Woodland (WWB) map class. Further discussion is provided above in the Users' Accuracy of WWB section.

Three other AA sites were mapped with the Douglas-fir Woodland (WDF) map class, due to either a misinterpretation of tree species or an incorrect interpretation regarding the RD of limber pine present (interpreted too high of RD). Typically, but not always, the limber pine is discernable from Douglas-fir by its branching pattern and light grey color.

One additional AA site was mapped with the Subalpine Fir - Engelmann Spruce Woodland (WFS) map class. Again, this is probably because of misinterpreting the RD of limber pine present.

Douglas-fir Forest (FDF) Map Class

Both the users' and producers' accuracy for the Douglas-fir Forest (FDF) map class are slightly low, each with their upper confidence intervals exceeding the standard; users' accuracy is 79% with a 90% confidence interval of 67–91% (n = 38), and producers' accuracy is 77% with a 90% confidence interval of 65–89% (n = 39).

Although Douglas-fir has a distinguishable signature on the aerial photographs, using the FDF map class to map Douglas-fir forest was more discernable when Douglas-fir clearly dominated the tree canopy. As the forest canopy becomes more mixed with other conifers, it became increasingly difficult to determine the proper map class based on decision rules (e.g., FDF map class with as low as 25% Douglas-fir RD to as much as 75% RD of lodgepole pine and/or western larch).

Users' Accuracy of FDF

Of the 38 AA sites located in polygons classified as FDF, 8 were classified by the AA field crews as vegetation types represented by map classes other than the FDF map class.

Four of these eight AA sites were classified as vegetation types belonging to Sublalpine Fir - Engelmann Spruce Forest (FFS) map class. These were due to incorrectly delineating the polygons (the polygons could have been delineated differently to properly capture both vegetation types in the area).

Two other AA sites were classified as vegetation types belonging to the Lodgepole Pine Forest (FLP) map class. These were due to mistaken identity. At times, it was quite difficult distinguishing between lodgepole pine and Douglas-fir on the aerial photographs; at certain locations, the photo signatures were of similar appearance, particularly to the tight-crowned forest stands (doghair).

Two additional AA sites were classified as vegetation types belonging to the Western Larch Forest (FWL) and the Ponderosa Pine Forest (WPP) map classes. In each instance, an area dominated by western larch or ponderosa pine could have been mapped.

Producers' Accuracy of FDF

Of the 39 AA sites classified by the AA field crews as vegetation types represented by the FDF map class, 9 were mapped with a map class other than the FDF map class.

These nine AA sites were mapped with several other map classes: two with Subalpine Fir - Engelmann Spruce (FFS), three with Western Larch Forest (FWL), one with Cedar Hemlock Forest (FCH/FCS), one with Whitebark Pine Woodland (WWB), one with Douglas-fir Woodland (WDF), and one with Subalpine Fir - Engelmann Spruce Woodland (WFS).

Generally, errors in map classification to these other forest and woodland types were probably because of differences in RD perspectives; the mapper interprets cover over a large area, while the AA field crews estimates cover over a much smaller area. The different perspectives often lead to different conclusions in determining the proper vegetation type or map class. The errors to FWL actually reflect conventional differences between the vegetation classification and the map classification, having varying RD rules for each.

Douglas-Fir Woodland (WDF) Map Class

The producers' accuracy (86%, n = 28) for the Douglas-fir Woodland (WDF) map class is above accuracy standard, but the users' accuracy is low with the upper confidence intervals exceeding the standard (73% with a 90% confidence interval of 58–87%, n = 33).

Users' Accuracy of WDF

Of the 33 AA sites located in polygons classified as WDF, 9 were classified by the AA field crews as vegetation types represented by map classes other than the WDF map class.

Three of the nine AA sites were classified as vegetation types belonging to the Limber Pine Woodland (WLM) map class. During mapping, either the tree species were misinterpreted or the RD of limber pine was incorrectly determined (RD interpreted too low). Usually limber pine is discernable from Douglas-fir by its branching pattern and light grey color. However, when Douglas-fir mortality can resemble this branching of limber pine on the aerial photographs.

Two of the AA sites were classified as vegetation types belonging to the Lodgepole Pine Woodland (WLP) map class. As discussed above in the Users' Accuracy of FDF, distinguishing open-growth forms of lodgepole pine from Douglas-fir becomes a challenge, along with the conventional rules regarding RD between the two tree species.

One AA site was classified as a vegetation type belonging to the Douglas-fir Forest (FDF) map class, which is not too surprising given the ecotonal overlap between forest and woodland characteristics.

Three other AA sites were classified as vegetation types belonging to other map classes: one to Mixed Conifer - Deciduous Forest (FEP), one to Cedar Hemlock Forest (FCH/FCS), and one to Subalpine Fir - Engelmann Spruce Woodland (WFS). These errors are most likely the result of misinterpreting the RD among tree species in order to assign the proper map class.

Western Larch Forest (FWL) Map Class

The producers' accuracy (86%, n = 22) for the Western Larch Forest (FWL) map class is above standard, but the users' accuracy is low with the upper confidence interval exceeding the standard (76% with a 90% confidence interval of 60–92%, n = 25).

Users' Accuracy of FWL

Of the 25 AA sites located in polygons classified as FWL, 6 were classified by the AA field crews as vegetation types represented by map classes other than the FWL map class.

These six AA sites were classified as vegetation types belonging to several map classes: one to Lodgepole Pine Forest (FLP), three to Douglas-fir Forest (FDF), and two to Subalpine Fir - Engelmann Spruce Forest (FFS). Some of these errors were caused by disparity between vegetation classification and map classification conventions.

Engelmann Spruce Forest (FSP) Map Class

The producers' accuracy (88%, n = 24) for the Engelmann Spruce Forest (FSP) map class is above standard, but the users' accuracy is low with the upper confidence interval exceeding the standard (78% with a 90% confidence interval of 60–92%, n = 27).

Users' Accuracy of FSP

Of the 27 AA sites located in polygons classified as FSP, 6 were classified by the AA field crews as vegetation types represented by map classes other than the FSP map class.

Five of these six AA sites were classified as vegetation types belonging to the Subalpine Fir - Engelmann Spruce (FFS) map class. This error is largely due to misinterpreting the RD of subalpine fir present in the forest stand; when interpreting the FSP map class, the RD of fir is <25% to other tree species.

One AA site was classified as a vegetation type belonging to the Deciduous Wet Shrubland (SWL) map class. In this instance, the cover density of Engelmann spruce was estimated too high during photointerpretation—the spruce was estimated >25% total cover to the area.

Accuracy Results: Waterton Lakes National Park and Environs Map Coverage

The AA revealed an overall accuracy of 76.8% including the kappa adjustment for chance agreements (90% confidence interval of 72.0–81.6%, n = 231), somewhat below the VMP requirement of 80%. Several individual map class accuracies are also below the desired 80% accuracy standard. The greatest concentrations of both commission errors (users' accuracy) and omission errors (producers' accuracy) occurred primarily in the forest and woodland map classes. In addition, the total number of AA samples for the WLNP and environs was relatively small, resulting in most map classes having low sample frequency and broad confidence intervals. Due to the low number of samples, the assessment provides a lesser degree of useful or accurate information regarding the accuracy of the vegetation map. Additional AA sites are necessary for more definite results regarding accuracy of individual map classes. Nevertheless, below we briefly summarize the map classes having lower users' and/or producers' accuracies for the WLNP and environs map coverage.

Subalpine Fir - Engelmann Spruce Forest (FFS) Map Class

The users' accuracy (80%, n = 19) for the Subalpine Fir - Engelmann Spruce (FFS) map class just meets accuracy standard, but the producers' accuracy is low with the uppermost confidence interval barely exceeding the standard (63% with a 90% confidence interval of 42–84%, n = 15).

Producers' Accuracy of FFS

Of the 15 AA sites classified by the AA field crews as vegetation types represented by the FFS map class, 7 were mapped with a map class other than FFS: two with Lodgepole Pine Forest (FLP), two with Douglas-fir Forest (FDF), one with Engelmann Spruce - Wet Shrub Forest (FSW), one with Douglas-fir Woodland (WDF), and one with Subalpine Larch Woodland (WSL).

Subalpine Fir - Engelmann Spruce Woodland (WFS) Map Class

The users' accuracy (83%, n = 6) for the Subalpine Fir - Engelmann Spruce Woodland (WFS) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval exceeding the standard (63% with a 90% confidence interval of 28–97%, n = 8).

Producers' Accuracy of WFS

Of the eight AA sites classified by the AA field crews as vegetation types represented by the FFS map class, three were mapped with a map class other than WFS: two with Whitebark Pine Woodlands (WWB) and one with Subalpine Fir - Engelmann Spruce Forest (FFS).

Whitebark Pine Woodland (WWB) Map Class

The producers' accuracy (100%, n = 7) for the Whitebark Pine Woodland (WWB) map class is well above accuracy standard, but the users' accuracy is low with the uppermost confidence interval exceeding the standard (70% with a 90% confidence interval of 41–99%, n = 10).

Users' Accuracy of WWB

Of the 10 AA sites located in polygons classified as WWB, 3 were classified by the AA field crews as vegetation types represented by map classes other than WWB: two with Subalpine Fir - Engelmann Spruce Woodland (WFS) and one with Subalpine Larch Woodland (WSL).

Lodgepole Pine Woodland (WLP) Map Class

The users' accuracy (100%, n = 2) for the Lodgepole Pine Woodland (WLP) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval exceeding the standard (50% with a 90% confidence interval of -4–104%, n = 4). Few sites were collected for assessment of users' and producers' accuracy, resulting in quite broad confidence intervals.

Producers' Accuracy of WLP

Of the four AA sites classified by the AA field crews as vegetation types represented by the WLP map class, two were mapped with the Douglas-fir Woodland (WDF) map class. It goes to reason that open growth characteristics of lodgepole pine and Douglas-fir can be quite similar, making the mapping of these woodlands a challenge when determining RD of each tree species.

Poplar - Birch Forest (FAP) Map Class

The users' accuracy (92%, n = 13) for the Poplar - Birch Forest (FAP) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval exceeding the standard (75% with a 90% confidence interval of 54–96%, n = 16).

Producers' Accuracy of FAP

Of the 16 AA sites classified by the AA field crews as vegetation types represented by the FAP map class, 4 were mapped with a map class other than the FDF map class: one with Subalpine Fir - Engelmann Spruce Forest (FFS), one with Douglas-fir Woodland (WDF), one with Deciduous Shrubland: Dry - Mesic (SDS), and one with Deciduous Wet Shrubland (SWL). The two polygons mapped in error to conifer map classes, FFS and WDF, may be due to the inability to clearly see the deciduous canopy on the 1999 TC contact prints. The polygon mapped in error to the SDS map class was due to short deciduous trees that were difficult to discern and were mistaken for shrubs. The polygon mapped in error to the SWL map class was mistaken for wet shrubs rather than short aspen.

Mixed Conifer - Deciduous Forest (FEP) Map Class

The users' accuracy (93%, n = 15) for the Mixed Conifer - Deciduous Forest (FEP) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval just reaching the standard (61% with a 90% confidence interval of 42–80%, n = 23).

Producers' Accuracy of FEP

Of the 23 AA sites classified by the AA field crews as vegetation types represented by the FEP map class, 9 were mapped with a map class other than the FDF map class: four with Engelmann Spruce Forest (FSP), three with Douglas-fir Woodland (WDF), one with Douglas-fir Forest (FDF), and one with Mixed Conifer - Deciduous Wet Forest (FWM).

Douglas-fir Forest (FDF) Map Class

The producers' accuracy (100%) for the Douglas-fir Forest (FDF) map class is well above the accuracy standard, but the users' accuracy and the uppermost confidence interval is well below the standard (36% with a 90% confidence interval of 8–65%, n = 11).

Users' Accuracy of FDF

Of the 11 AA sites located in polygons classified as FDF, 7 were classified by the AA field crews as vegetation types represented by map classes other than FDF: two with Subalpine Fir - Engelmann Spruce Forest (FFS), one with Lodgepole Pine Forest (FLP), one with Engelmann Spruce Forest (FSP), one with Poplar - Birch Forest (FAP), and one with Mixed Conifer - Deciduous Forest (FEP). Usually, the errors were due to polygons needing more detail; the polygons could have been split into other map classes, even though part of the polygons may be correct with the FDF map class.

Douglas-Fir Woodland (WDF) Map Class

Both the users' and producers' accuracy for the Douglas-Fir Woodland (WDF) map class are below accuracy standard, with the upper confidence interval for user's accuracy not quite reaching the standard, but the upper confidence interval for producers' accuracy exceeding the standard; users' accuracy is 46% with a 90% confidence interval of 20–73% (n = 13), and producers' accuracy is 67% with a 90% confidence interval of 35–98% (n = 9).

Users' Accuracy of WDF

Of the 13 AA sites located in polygons classified as WDF, 7 were classified by the AA field crews as vegetation types represented by map classes other than WDF: three with Mixed Conifer - Deciduous Forest (FEP), two with Lodgepole Pine Woodland (WLP), one with Subalpine Fir - Engelmann Spruce Forest (FFS), and one with Poplar - Birch Forest (FAP). For some of the FEP and FAP cases, the deciduous component was not obvious on the 1999 TC aerial photos prints. For others, the RD of conifers was in disagreement between photointerpretation and field data.

Producers' Accuracy of WDF

Of the nine AA sites classified by the AA field crews as vegetation types represented by the WDF map class, three were mapped with a map class other than WDF: two with Limber Pine Woodland (WLM) and one with Douglas-fir Forest (FDF).

Engelmann Spruce Forest (FSP) Map Class

Both the users' and producers' accuracy for the Engelmann Spruce Forest (FSP) map class are below accuracy standard, with the upper confidence interval for user's accuracy not quite reaching the standard, but the upper confidence interval for producers' accuracy exceeding the standard; users' accuracy is 33% with a 90% confidence interval of -7–73% (n = 6), and producers' accuracy is 67% with a 90% confidence interval of 5–128% (n = 3). Few sites were collected for assessment of users' and producers' accuracy, resulting in broad confidence intervals.

Users' Accuracy of FSP

Of the six AA sites located in polygons classified as FSP, four were classified by the AA field crews as vegetation types represented by the Mixed Conifer - Deciduous Forest (FEP) map class.

Producers' Accuracy FSP

Of the three AA sites classified by the AA field crews as vegetation types represented by the FSP map class, one was mapped with the Douglas-fir Forest (FDF) map class. Upon review, the polygon of FDF could have been broken into several forest types, including a streamside stretch of FSP.

Engelmann Spruce - Wet Shrub Forest (FSW) Map Class

The producers' accuracy (100%, n = 2) for the Engelmann Spruce - Wet Shrub Forest (FSW) map class is well above accuracy standard, but the users' accuracy is low with the uppermost confidence interval exceeding the standard (67% with a 90% confidence interval of 5–128%, n = 3). Again, few sites were collected for assessment of both users' and producers' accuracy, resulting in broad confidence intervals.

Users' Accuracy of FSW

Of the three AA sites located in polygons classified as FSW, one was classified by the AA field crews as a vegetation type represented by the Subalpine Fir - Engelmann Spruce (FFS) map class.

Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial (SAM) Map Class

Both the users' and producers' accuracy for the Mixed Conifer - Deciduous Shrubland: Avalanche/Snow Burial (SAM) map class are below accuracy standard, with the upper confidence interval for the user's and producers' accuracy exceeding the standard; users' accuracy is 75% with a 90% confidence interval of 27–123% (n = 4), and producers' accuracy is 43% with a 90% confidence interval of 5–81% (n = 4). Once again, very few sites were collected for assessment of users' accuracy and producers' accuracy, resulting in broad confidence intervals.

Users' Accuracy of SAM

Of the four AA sites located in polygons classified as SAM, one was classified by the AA field crews as a vegetation type represented by the Deciduous Shrubland: Avalanche/Snow Burial (SAD) map class. Upon further review, there were neither enough conifers appearing on the aerial photo nor on the data sheet to justify the SAM map class.

Producers' Accuracy of SAM

Of the seven AA sites classified by the AA field crews as vegetation types represented by the SAM map class, five were mapped with a map class other than SAM: two with Dwarf-shrub/Herbaceous Complex: Dry - Mesic (CSA), one with Subalpine Fir - Engelmann Spruce Woodland (WFS), and one with Subalpine Larch Woodland (WSL). All of these were interpretive errors.

Deciduous Shrubland: Dry - Mesic (SDS) Map Class

The users' accuracy (82%, n = 11) for the Deciduous Shrubland: Dry - Mesic (SDS) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval exceeding the standard (69% with a 90% confidence interval of 44–94%, n = 13).

***Producers' Accuracy* of SDS**

Of the 13 AA sites classified by the AA field crews as vegetation types represented by the SDS map class, four were mapped with a map class other than SDS: two with Grassland Herbaceous (HGL), one with Poplar - Birch Forest (FAP) and one with Mixed Conifer - Deciduous Forest (FEP).

Exposed Shoreline Herbaceous: Pioneering Vegetation (HES) Map Class

The producers' accuracy (100%, n = 2) for the Exposed Shoreline Herbaceous: Pioneering Vegetation (HES) map class is well above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval just reaching the standard (40% with a 90% confidence interval of -6–86%, n = 5). Once again, few sites were collected for assessment of both users' and producers' accuracy, resulting in broad confidence intervals.

Users' Accuracy of HES

Of the five AA sites located in polygons classified as HES, three were classified by the AA field crews as vegetation types represented by map classes other than HES: one with Mixed Conifer - Deciduous Forest (FEP), two with Lodgepole Pine Woodland (WLP), one with Deciduous Wet Shrubland (SWL), one with Grassland Herbaceous (HGL), and one with Wet Meadow Herbaceous (HWM). All of these were interpretation errors.

Dwarf-shrub/Herbaceous Complex: Mesic - Wet (CSW) Map Class

The producers' accuracy (100%, n = 4) for the Dwarf-shrub/Herbaceous Complex: Mesic - Wet (CSW) map class is well above accuracy standard, but the users' accuracy is low with the uppermost confidence interval just reaching the standard (67% with a 90% confidence interval of 27–107%, n = 6). The few sites collected for assessment of both users' and producers' accuracy resulted in the broad confidence intervals.

Users' Accuracy of CSW

Of the six AA sites located in polygons classified as CSW, two were classified by the AA field crews as vegetation types represented by map classes other than CSW: one with Deciduous Shrubland: Avalanche/Snow Burial (SAD) and one with Grassland Herbaceous (HGL). These were both interpretive errors.

Bearberry Dwarf-shrubland (DBB) Map Class

The users' accuracy (100%, n = 2) for the Deciduous Shrubland: Dry - Mesic (SDS) map class is above accuracy standard, but the producers' accuracy is low with the uppermost confidence interval exceeding the standard (67% with a 90% confidence interval of 5–128%, n = 3). Again, the few sites collected for assessment of both users' and producers' accuracy resulted in the broad confidence intervals.

Producers' Accuracy of DBB

Of the three AA sites classified by the AA field crews as vegetation types represented by the DBB map class, one was mapped with the White Dryad Dwarf-shrubland (DWD) map class. The two map classes, DBB and DWD, closely resemble one another and differ primarily by elevation. In this instance, however, a vegetation type represented by the DBB map class was actually found where normally vegetation types represented by DWD would be expected, thus resulting in this error.

Discussion

Accuracy requirements for the VMP specify an 80% accuracy for both the collective map classes and for each individual map class (theme) representing NVC plant communities (associations). An AA is accomplished through field data collection using a stratified random sampling design, with subsequent comparison to the mapped polygons. Errors occur when map classes assigned to the polygons do not agree with the vegetation types observed from the field sampling. While this sounds straightforward, in actuality it is not, in part because a major assumption of AA is violated—the assumption that the mapping process and the assessment process are identical, thus false errors do not occur because of procedural differences. The AA procedure, however, is based on field observance, while the procedure of mapping is based on aerial photointerpretation. The two different perspectives each have inherent subjectivity that naturally leads to disagreements when compared to one another. The disagreements do not necessarily mean one perspective is right and the other is wrong. Thus, the usefulness of traditional statistical analysis methods to determine the accuracy is limiting because definitions of "error" and "accuracy" within this traditional framework leave no room to account for interpretive judgment calls that are inherent to both mapping and field data collection.

In concluding the analysis, we had subjected the AA data to a lengthy review process to overcome the majority of inherent shortcomings. This allowed us to determine a realistic estimate of the thematic assessment. Although we have conducted AA analysis with several other mapping projects in the past, we have not yet discovered a better way of comparing the two data sets. Thus, we found ourselves faced with many hours of discerning problems and correcting false errors. These scenarios included investigating coordinates placed in unfavorable spots, thus making it difficult, if not impossible, to classify mapped polygons (even generalizing average canopy covers of species occurring across a variety of plant assemblages are separated by subjective decisions of relative cover). Our efficiency during the analysis process was broken into seemingly non-ending piles of data sheets and aerial photos as we tried to discern each scenario. Yet, the alternative of conducting a purely mechanized comparison and simply reporting the results would be less favorable since the results would be calculated with many false errors and indubitably fail in meeting VMP accuracy requirements.

Project leaders from other mapping teams have suggested that the VMP adopt a multi-level AA with fuzzy logic, and incorporate these analyses into the entire AA process (e.g., the Grand Teton National Park Vegetation Mapping Project). At a minimum effort, it seems worthy of a program-wide discussion to decide if fuzzy logic analyses is important information to users as well as producers of the map, and to explore whether program-wide routines might result in cost savings.

We were aware that training field crews and spending several days in the field would allow for better understanding and knowledge of the AA field process. In fact, we realized that more field time could have been spent with the AA crews to circumvent many issues that were later discovered during the analysis. These issues ranged from finding too many sites that were inclusions (areas too small to map) to poorly taken ground photos of the sites. A review of procedures is needed, especially when data are collected over several seasons, as was with our case.

A decision was made by the park staff and mapping team to sample areas of low burn severity in the Phase III field effort. To capture these areas of low burn severity, we realigned our original Phase III mapping effort to map areas of recent burn (post-aerial photo, August 1999) and forfeited areas not recently burned, but certainly within the accessible zone for AA crews to safely and easily access (e.g., the northwest tier of GNP along Kintla Lake and above). It quickly became apparent during the Phase III field season, that field crews were unable to sample many of the low burn severity areas due to safety concerns (e.g., falling trees) while passing through high burn severity areas. We suggest for future mapping projects not to consider performing AA within low burn severity sites that are completely encircled with areas of high burn severity. In fact, performing AA within any recently burned area should be questioned regarding safety and best use of effort.

Another issue that affected AA results was not having the vegetation keys completed prior to the establishment of mapping conventions and rules. This inherently created discrepancies between the vegetation and map classifications that were made apparent during the AA process. For example, errors occurred when mapping conventions for relative canopy cover differed from those of the vegetation keys.

Lastly, some errors recognized in the AA process simply occurred due to the nature of the data. Many plant species occur in multiple associations, and it takes only a small disparity in the subjective estimate of relative cover values to result in differences. Also, since the area of the field site is often a small area within a larger polygon, the relative canopy cover at the field site may actually be different from the rest of polygon, resulting in an error (except when the field site was an obvious inclusion).

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