

# Vegetation classification, mapping, and monitoring at Voyageurs National Park, Minnesota: An application of the U.S. National Vegetation Classification

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## Abstract

**Question:** How can the U.S. National Vegetation Classification (USNVC) serve as an effective tool for classifying and mapping vegetation, and inform assessments and monitoring?

**Location:** Voyageurs National Park, northern Minnesota, U.S.A and environs. The park contains 54 243 ha of terrestrial habitat in the sub-boreal region of North America.

**Methods:** We classified and mapped the natural vegetation using the USNVC, with 'alliance' and 'association' as base units. We compiled 259 classification plots and 1251 accuracy assessment test plots. Both plot and type ordinations were used to analyse vegetation and environmental patterns. Color infrared aerial photography (1:15840 scale) was used for mapping. Polygons were manually drawn, then transferred into digital form. Classification and mapping products are stored in publicly available databases. Past fire and logging events were used to assess distribution of forest types.

**Results and Discussion:** Ordination and cluster analyses confirmed 49 associations and 42 alliances, with three associations ranked as globally vulnerable to extirpation. Ordination provided a useful summary of vegetation and ecological gradients. Overall map accuracy was 82.4%. *Pinus banksiana* - *Picea mariana* forests were less frequent in areas unburned since the 1930s.

**Conclusion:** The USNVC provides a consistent ecological tool for summarizing and mapping vegetation. The products provide a baseline for assessing forests and wetlands, including fire management. The standardized classification and map units provide local to continental perspectives on park resources through linkages to state, provincial, and national classifications in the U.S. and Canada, and to NatureServe's Ecological Systems classification.

**Keywords:** Accuracy assessment; Alliance; Association; Fire; International Vegetation Classification; Logging; Map legend; National Park Service Vegetation Mapping Program; Ordination.

**Abbreviations:** USNVC = United States National Vegetation Classification; VMP = Vegetation Mapping Program of the United States Geological Survey - National Park Service; NP = National Park.

## Introduction

A primary goal of vegetation classification is to arrange vegetation patterns into an ecologically meaningful set of types, with clear diagnostic criteria for identifying the types. Classification also serves to facilitate communication and information-gathering about ecological resources, document the diversity of ecological communities, and provide a framework for addressing scientific inquiries into the patterns of vegetation. There is now a rich and ongoing tradition of developing and applying classification for these purposes, relying in particular on the concepts of 'alliance' and 'association' that have long informed the development of vegetation units in Europe and elsewhere (Westhoff & van der Maarel 1973; Specht et al. 1974; Rodwell et al. 2002). Despite some reticence in Anglo-American countries to formalize classification efforts, the growing need for this approach has led to a renewed interest in that tradition, but also to a re-thinking of older concepts and methodologies (Rodwell 1991; Loucks 1996; Jennings et al. 2004). These new initiatives have helped shape the U.S. National Vegetation Classification (USNVC) and other national efforts that share the common framework of the International Vegetation Classification (IVC) (Anon. 1997b; Grossman et al. 1998; Areces-Mallea et al. 1999; Alvo & Ponomarenko 2003; Jennings et al. 2004; Anon. 2006). Projects in the U.S. are under way to meet the challenge of using the new concepts and tools for classification, addressing both scientific inquiry and applications to conservation and resource management. These projects are demonstrating the values of a standardized, yet dynamic, classification system. We emphasize here, not the debates over the relative merits of classification per se, but the merits of applying a standardized classification in the context of conservation and resource management applications.

One of the primary concerns for any vegetation clas-

sification is its ability to serve as a guide for mapping. For many ecologists and practitioners, the merits of a classification are judged by how mappable it is. This is because the very basic questions of 'Where is it', 'How much of it is there', and 'How is it changing?' are frequently addressed through mapping. Yet, because mapping can be done at any scale and with different technologies, the use of a classification for mapping partially becomes a function of the technology that is used. Thus, vegetation ecologists have long recognized that classification types and map unit types are separate, if related, units. Nonetheless, any classification also needs to establish the spatial and structural characteristics of the vegetation types being defined, and field investigations that require mapping the vegetation can serve as an important test of the classification.

In the U.S., the use of the USNVC by federal agencies facilitates effective resource stewardship by providing a common language for reporting vegetation information across federal lands. Its use by state and other non-federal partners further increases its utility to address scientific, resource management and conservation issues. Here we address these uses by presenting the methodology used to classify and map the vegetation on national park lands managed by the U.S. National Park Service (NPS). Our objectives are: (1) to demonstrate how the USNVC classification is developed and applied to guide the mapping process at Voyageurs National Park, Minnesota, USA, and (2) to test the accuracy and applications of the map, both in terms of a standard accuracy assessment, and in describing the response of current vegetation to past logging and fire disturbances. We conclude by noting other ways that the classification and map products provide information useful for monitoring and assessment of national park resources. Elsewhere, we discuss in more detail the methods that are used to map the park (see Hop et al. 2001).

## Background

### *The USGS - NPS Vegetation Mapping Program*

The U.S. Geological Survey - National Park Service (USGS - NPS) Vegetation Mapping Program (VMP) is ambitious in scope and unique in vision. For the first time in the history of land management in the United States, this project provides a means to map vast acreages – the 270 National Park System units – using a single vegetation classification and mapping standard. The objective is to classify, describe, and map plant communities for most of the park units within the National Park Service (NPS), typically with a minimum mapping unit of 0.5 ha and 1:12 000 or 1:15800 color-infrared aerial photog-

raphy (Grossman et al. 1994). Field and lab teams that work in each park are expected to follow standardized field sampling and mapping protocols. Products for each park include digital files of the vegetation field data and map, keys and descriptions to plant communities (associations), reports, metadata, map accuracy verification summaries, and aerial photographs. For more information on the VMP, visit <http://biology.usgs.gov/npsveg/>

### *The U.S. National Vegetation Classification and Park Mapping Standards*

The USNVC is the recognized standard for *reporting* of all vegetation classification and mapping projects by U.S. federal agencies (Anon. 1997b). The classification is a hierarchical system with physiognomic units at the higher levels of the hierarchy and floristic units at the lower levels (Anon. 1997b; Grossman et al. 1998). Currently, federal requirements for reporting to the standard apply to the five physiognomic levels (formations). New federal standards are being developed for the floristic units, based on guidelines from the Ecological Society of America's Vegetation Classification Panel (Jennings et al. 2004). In the meantime, agencies are encouraged to aid in the development of the floristic (alliance and association) levels, which have been developed and are periodically enhanced by the ongoing work of NatureServe, the network of Heritage Programs, and federal, academic and other partners (Anon. 2006).

The National Park Service contains park units that span the continent, so inventories of the park resources required a balance between local and national perspectives. A consistent classification was needed on which to base each park map in order to allow map products to be comparable throughout the country. For this reason, the VMP program chose the USNVC, seeking to balance the needs of mapping local vegetation patterns in national parks, with the overall need to achieve consistency between parks, and between adjacent federal lands.

The VMP calls for mapping to the association level, or else the alliance level, which may be more accurately mapped. Voyageurs National Park, one of the first national parks to be mapped, provided a test of the mapping and classification standards proposed for the program.

### *Voyageurs National Park*

Voyageurs National Park was authorized in 1971 and established in 1975. The park extends for over 50 km along the Canadian - United States international border, from 29 km east of International Falls to the western edge of the Boundary Waters Canoe Area (BWCA) in the Superior National Forest (Fig. 1). The park covers 88 244 ha (218 055 acres), of which 61.6% is land, the

rest open lakes and ponds. Four large lakes comprise the majority of the water area. The climate is mid-continental, with a mean annual temperature of 1.4 °C, annual extremes that may exceed -40 and 36 °C, and a mean annual precipitation of 630 mm (Kurmis et al. 1986). The landscape is rugged Canadian Shield terrain, consisting of Early Precambrian granite (more common in the southern part of the park), biotite schist (metasedimentary rock more common in the north), and migmatite (interlayered granite and biotite). A greenstone belt outcrop occurs in a limited region of the northwestern part of the park. Mafic dikes occur in localized areas. Prolonged erosion and glacial scouring during the Pleistocene have produced the current surficial geology features, which include sandy loam tills, lacustrine deposits (particularly on the western edge from glacial Lake Agassiz, but also in localized lowlands and bedrock depressions), and localized outwash deposits of sand and gravel (Okajangas & Matsch 1982).

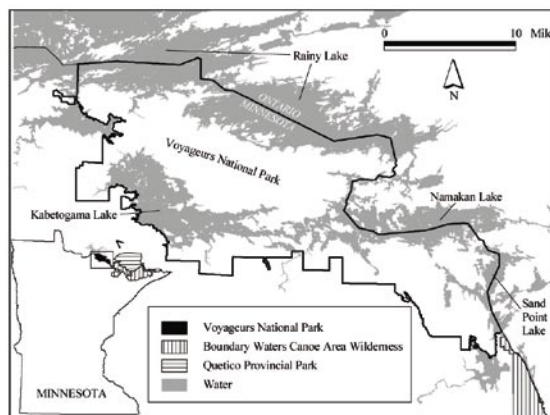
Soils formed in the glacial deposits range from thin, loamy, and well drained, often in raised areas with bedrock outcrops, to thick, clayey, and poorly drained low-lying areas (Kurmis et al. 1986). The topography of the area is a complex pattern of low ridges and valleys, with a maximum relief of 90 m (Johnston & Naiman 1990), but more typically 20 to 30 m.

#### *Fire and logging disturbances*

Voyageurs National Park is mandated to manage the landscape as it was during the time of fur-trapping Voyageurs (1730s-1860s), essentially to manage for natural processes (Windels et al. in prep.). Prior to settlement and logging, the vegetation consisted of jack pine forests with rocky outcrops, white and red pine forests, spruce-fir and aspen forests, black spruce-tamarack bogs

and swamps, fens, wet meadows, marshes, and aquatics (Kurmis et al. 1986). Periodic fires both before and after settlement favored the fire-dependent pines, as well as the aspen-birch forests. Based on analyses from the adjacent BWCA (Heinselman 1996), fires could sweep through thousands of acres at a time. Heinselman's work indicated that, in broad terms, upland *Pinus banksiana* - *Picea mariana* (jack pine - black spruce) stands in the BWCA had high-crown fires or intensity surface burns with an average fire return interval every 50-75 years, *Picea glauca* - *Abies balsamea* - *Populus tremuloides* (white spruce - balsam fir - trembling aspen) stands had high intensity surface fires or partial canopy fires every 70-110 years, and *Pinus resinosa* - *Pinus strobus* (red pine - white pine) stands generally had more frequent low-intensity surface fires every 5 to 100 year intervals, with high intensity, stand replacing fires every 150- 350 years. Windstorms, spruce-budworm disease, herbivores, and beaver activity are other natural disturbance factors acting in the park. (Johnston & Naiman 1990; Crowley 1995).

From 1875 to the 1970s, a combination of continued natural fires, some fire suppression and logging disturbed the forests (Fritz 1986). Logging operations initially (1875-1940s) focused on cutting of white pine and red pine for saw timber (which often led to replacement by aspen), but later switched to cutting of spruce, fir, aspen and other hardwoods for pulp operations. Although logging has impacted much of the park, it has had a minor impact on the forests of the central roadless core of the park, the Kabetogama Peninsula (see Fig. 1). Extensive natural wildfires occurred there in 1923 and 1936, and perhaps as much as 25% of the Peninsula was logged during the 1950s and 1960s, prior to park establishment (J. Pastor, testimony for the U.S. House of Representatives, October 28, 1995).



**Fig. 1.** Location of Voyageurs National Park in Northern Minnesota. The Kabetogama Peninsula occupies the central land mass between Rainy Lake and Kabetogama Lake.

## Methods

### *Aerial photograph acquisition*

Most of the northern one-third of the project area was flown on September 27, 1995. The remaining area was flown in 1996 (September 13, 14, and October 3). The 22.9 cm × 22.9 cm photos were taken at a scale of 1:15 800 using color infrared (CIR) photography (approximately 6.4 cm to a km). Each photo had about 30% overlap between adjacent flight lines and 60% overlap along each flight line. An existing set of CIR photo prints, taken in the fall of 1988 at a scale of 1:12 000, was used as collateral information.

### *Preliminary classification list*

A preliminary list of 37 associations was generated for the park in 1996, using several sources, including a state classification maintained by the Minnesota Natural Heritage and Nongame Program (Anon. 1993; hereafter Minnesota Program), plant community publications in northwestern Ontario by Sims et al. (1997) and Harris et al. (1996), and other local studies. This early expert-derived list was expanded to include descriptions for each type, including characteristic species and habitat, and crosswalks to these other classifications (Faber-Langendoen 2001; Faber-Langendoen et al. 2007).

### *Reconnaissance and verification for mapping and classification*

The preliminary classification was field verified during the summer and fall of 1996. Teams of aerial photo-interpreters and ecologists collected brief descriptions (observation point data) on the plant communities they encountered in the field, and helped identify any diagnostic aerial photo signatures. Aerial photo 'validation' fieldwork was performed throughout the 1996 field season by the photo-interpretation team and ecologists in order to learn, test, and verify photo signatures, and develop a stable set of mapping protocols for delineating polygons for the northern third of the project area. In 1997 the process was extended to the rest of the project area, emphasizing photo signatures not previously observed.

### *Vegetation sampling and analysis for classification development*

The mapping project included the land surface of Voyageurs National Park and environs around the park, for a total area mapped of 1569 km<sup>2</sup>. The park was stratified into three areas: the western peatland area (Rat Root River peatland, which falls mostly outside the park boundaries but within the project area), the northern unit, where the bedrock is primarily biotite schist, with local areas of greenstone, and a southern unit, where the bedrock is primarily granite (the Vermilion granitic complex) (Okajangas & Matsch 1982). Reconnaissance and sampling was focused on the first two areas in the first year (1996), and on the third area in subsequent years.

Plot sampling was generally limited to an average of three plots per type, based on VMP specifications, but less well-understood types were sampled more extensively. Plots were selected to cover the distribution of types across the three stratified areas, based in some cases on random selection of stands from preliminary photosignatures of types in an area. Plots were placed

subjectively in the most representative part of a selected stand. A total of 191 plots were collected for the project, and 68 additional plots were added from surveys by Kurmis et al. (1986) and the Minnesota Program. An additional 1251 accuracy assessment (test) plots were also collected (see *Accuracy assessment* below).

Plot sizes were 20 m × 20 m for forests and woodlands and 10 m × 10 m for shrublands, herbaceous, and nonvascular vegetation. The vegetation was divided into strata (tree, shrub/sapling, herb, nonvascular), and height and cover abundance of each stratum and its major growth forms was estimated. All the species in each stratum were listed and cover was estimated using the 7-point Braun-Blanquet cover scale (Jennings et al. 2004). Additional species within the vegetation unit or polygon that occurred outside of sampled plots (generally within 2 m of the plot border) were noted. Species that were not identifiable in the field were collected for later identification. Environmental information was also recorded on field forms, including: surficial geology, hydrologic (flooding) regime, soil drainage regime, soil texture and depth, slope, aspect, topographic position, and evidence of disturbance. These data was used to generate four main variables – slope, elevation, aspect, and soil depth (four categories – shallow soils over bedrock, mineral soil, shallow peat, deep peat). The X-Y coordinates of each plot were recorded in Universal Transverse Mercator (UTM) projection (Zone 15) and North American Datum of 1983 (NAD83) using a Rockwell Precision Lightweight GPS Receiver (PLGR) and, on occasion, a Trimble GPS unit. Other location information was also recorded.

Vegetation plot data were entered into the Minnesota Program's plot database. Species were first assigned standardized state codes and names and then converted to nationally standardized nomenclature and codes in the PLANTS database (Anon. 1999). These data were transferred to the PLOTS database (Anon. 1997a) and subsequently to VegBank, a publicly viewable vegetation plots archive ([www.vegbank.org](http://www.vegbank.org)), where many plots supporting the USNVC are stored (Jennings et al. 2004).

Vegetation data were analysed using both ordination and cluster methods, including Non-metric Multidimensional Scaling (NMS), Detrended Correspondence Analysis (DCA) and Flexible Beta Cluster Analysis, as implemented in the PC-ORD software (McCune & Mefford 1999). For the ordination methods, cover mid-point data were first relativized by species maxima, then transformed using arcsine-square root. This transformation places greater emphasis on the less abundant species in the data set. For NMS, analyses were run using a random starting configuration, with 15 runs of real data and 30 runs of randomized data (autopilot mode). Distances were calculated using Sørensen's Index. For DCA, the default settings were used (downweighting of rare species, seg-

ments = 26). Species in less than 3% of the dataset were removed to reduce potential noise. We compared the relative effectiveness of these two programs in handling the large gradients across the parks.

The ordinations of 259 plots were strongly skewed by the 26 marsh plots (Table 1, A24-A30). After removal of the marsh plots, the subsequent analyses further suggested a distinction between upland plots and wetland plots. Outlier analysis also suggested that a single rocky outcrop plot be removed, as well as three shrubby rock outcrop plots. Because the 21 wet mineral forest plots occupied the center of the ordinations, we included them in both the upland and wetland datasets. The final upland dataset consisted of 138 plots  $\times$  219 species, and the wetland dataset of 112 plots  $\times$  223 species. No plots were collected in the grassland type A35a, which was an uncommon disturbed type in the park. We tested for correlations of environmental factors with vegetation using the first three NMS axes.

Assignment of plots to associations was made by visual inspection of the ordinations and cluster analyses, relying on USNVC type descriptions in Faber-Langendoen (2001), and the crosswalked classifications in Minnesota and Ontario (Minnesota Dept of Natural Resources 2003; Harris et al. 1996; Sims et al. 1997). For example, the primarily hardwood plots of *Quercus ellipsoidalis* - *Quercus macrocarpa* - (*Pinus banksiana*) Rocky Woodland association (Northern Pin Oak - Bur Oak - (Jack Pine) Rocky Woodland) (with three map phases) were distinguished from the related conifer association (Boreal Pine Rocky Woodland) by the diagnostic dominance of the two broad-leaved oak species, and associated dry understory ground layer species. This type was crosswalked to the Bur Oak type in Ontario, and the Pin Oak Woodland (Bedrock) type in Minnesota.

Plots for each association were then combined to produce a type summary. Cover was averaged (based on midpoint of cover scales). Species occurring in  $\geq 20\%$  of the plots were retained (all species were retained for the 18 types with fewer than five plots). Vegetation and environmental characteristics of each type were summarized (App. 1). We then submitted the types as 'plots' in an ordination analysis, a common technique for summarizing vegetation patterns (Sims et al. 1997; Feoli et al. 2003). We used NMS, following the same approach as outlined above. The ordinations provide a test of the ability of the types to summarize the vegetation and environmental relationship. They also help display the relative similarity among the types and locate the position of the types along major vegetation/environmental gradients.

### *Creation of map units*

The relationship between vegetation mapping and classification of vegetation types is complex. Timing of the photo mission, types of film (e.g. true color or color infrared), scale, and resolution as well as characteristics of the vegetation itself all contribute to how accurately vegetation can be mapped. Having two sets of aerial photographs (fall 1995/1996 set and fall 1988 set) was helpful in developing vegetation map units, as each set captured slightly different phenological signatures among the dominant tree and shrub species.

The photo-interpretation and ecologist teams worked together to develop map units that were compatible with the vegetation types found within the project area. This required close collaboration during reconnaissance trips, 'ground-truth' field trips, and photo-interpretation work. We discussed structural, floristic, and habitat characteristics of the vegetation types encountered, comparing the types to their appearances on the photos. When plant communities were difficult to discern on the photographs, it was necessary to aggregate plant communities into map units that were still clearly interpretable with respect to their composition. For example, map unit Aspen-Birch Forest (AB) represents the NVC Aspen - Birch Forest Alliance, which contains two associations: Aspen - Birch Boreal Conifer Forest and Aspen - Birch - Red Maple Forest. A classification matrix was developed to illustrate the relationship between the map units and the associations (Hop et al. 2001). The final map units maintain a clear link between the associations and alliances (App. 2). In addition, a set of modifiers was used to provide additional information (when applicable) about the vegetation structure within the polygon being mapped, including canopy cover density, cover pattern, height of woody stems, and percent evergreen-deciduous, as these were thought useful for park-specific resource management needs. These modifiers were sometimes used to recognize map unit phases of an association; for example, BSL and BST represent the evergreen and mixed phases of the Black Spruce / Labrador Tea Poor Swamp Association (Table 1, App. 2).

Ground features were interpreted, delineated, and labeled with map codes onto the central parts of the clear photo overlays using a stereoscope over a light table, in 3-D. We spatially referenced the photo-interpreted data to USGS 1:12 000-scale digital orthophoto quadrangle maps (with 5 m accuracy) using manual zoom transfer scopes, and digitally automated the referenced line data using the ArcScan utility in ArcInfo® (Version 7.2.1, Patch 2, Environmental Systems Research Institute, Redlands, California). Additional map units were developed to cover cultural and aquatic land cover features not described by the USNVC, such as populated areas,

**Table 1.** List of associations found in Voyageurs National Park, organized by ecological systems. Associations are shown with standard common names and abbreviated codes (e.g., 2485 = CEGLO02485) used in the U.S. National Vegetation Classification. System names (with abbreviations) are local versions of formal ecological system types (Comer et al. 2003). The final column provides the map unit link to each association (see App. 3). Codes with a \* indicate associations that were both uniquely mapped and are part of complexes, codes with a \*\* indicate associations that were only mappable as part of a mosaic or complex. All other associations were mapped directly, sometimes with two or more map units based on structural or floristic variability.

Abbr.	Ecological System	Association (plant community type)	# Plots	Code	Map Unit Link		
BG	BOG	A1 Black Spruce Bog	8	2485	BSB		
		A2 Black Spruce / Leatherleaf Semi-treed Bog	6	5218*	LBC (BBX when mosaic/complex)		
		A3 Leatherleaf Bog	1	5278*	LB (BBX when mosaic/complex)		
PS	POOR SWAMP	A4 Black Spruce / Labrador Tea Poor Swamp	7	2454	BSL (evergreen) & BST (mixed)		
PF	POOR FEN	A5 Tamarack Scrub Poor Fen	1	5226	TF		
		A6 Leatherleaf Poor Fen	7	5277*	LB (basin) (BBX when mosaic/complex)		
		A7 Northern Sedge Poor Fen	5	2265	SPF		
RF	RICH FEN	A8 Bog Birch - Willow Shore Fen	7	5227	BBSF		
		A9 Leatherleaf - Sweet Gale Shore Fen	10	5228*	LSF (BBX when mosaic/complex)		
		A10 Boreal Sedge Rich Fen	1	2500	SPF		
RS	RICH SWAMP	A11 Wiregrass Sedge Shore Fen	4	5229**	SMX (shares)		
		A12 White Cedar - Boreal Conifer Mesic Forest	10	2449	WCU		
		A13 Trembling Aspen - Balsam Poplar Lowland Forest	5	5036	AL		
		A14 Black Ash - Mixed Hardwood Swamp	5	2105	BA		
		A15 White Cedar - Black Ash Swamp	1	5165	WCBA		
		A16 Black Spruce / Alder Rich Swamp	7	2452	BSAS		
		A17 White Cedar - (Mixed Conifer) / Alder Swamp	4	2456	WCS (swamp) & WCT (peat, with tamarack)		
WM	WET MEADOW - SHRUB SWAMP	A18 Northern Tamarack Rich Swamp	8	2471	TA		
		A19 Speckled Alder Swamp	4	2381	AS		
		A21 Dogwood - Pussy Willow Swamp	4	2186	DS		
		A22 Northern Sedge Wet Meadow	7	2257**	SMX (shares)		
		A23 Canada Bluejoint Eastern Meadow	5	5174*	BJ (SMX when mosaic/complex)		
		FM	FRESHWATER MARSH	A24 Midwest Cattail Deep Marsh	6	2233*	CM (DMX & SMX when mosaic/complex)
				A25 Eastern Reed Marsh	3	4141*	PM (DMX & SMX when mosaic/complex)
A26 Freshwater Bulrush Marsh	4			2225*	BM (DMX when mosaic/complex)		
A27 Water Horsetail - Spikerush Marsh	2			5258**	DMX (shares)		
A28 Wild Rice Marsh	3			2382*	WRM (DMX when mosaic/complex)		
RO	ROCKY OUTCROP / WOODLAND	A29 Midwest Pondweed Submerged Aquatic Wetland	5	2282*	PW (DMX and BBX when mosaic/complex)		
		A30 Northern Water Lily Aquatic Wetland	3	2562*	WL (DMX and BBX when mosaic/complex)		
		A31 Jack Pine / Lichen Rocky Barrens	1	2491	JPL		
		A32 Boreal Pine Rocky Woodland	16	2483	JPW (jack pine) & JPM (mixed pine)		
		A33 Northern Pin Oak - Bur Oak - (Jack Pine) Rocky Woodland	16	5246	OW (deciduous), JPOM (jack pine-oak), and MPH (mixed pine-oak)		
		A34 Mixed Aspen Rocky Woodland	13	2487	ABW		
		A35 Boreal Hazelnut - Serviceberry Rocky Shrubland	3	5197	UBS		
WR	NORTHERN PINE - (OAK) FOREST	A35a Poverty Grass Granite Barrens	0	5157	MGF		
		A36 Red Pine / Blueberry Dry Forest	8	2443*	RP (WRPA when mosaic with AB)		
		A37 Red Pine - Aspen - Birch Forest	2	2520**	WRPA (shares)		
		A38 White Pine - Aspen - Birch Forest	7	2479**	WRPA (shares)		
		A39 White Pine / Mountain Maple Mesic Forest	12	2445*	WP (WRPA when mosaic with AB)		
		A40 Jack Pine / Balsam Fir Forest	3	2437*	JPF (JPAX when mosaic with AB)		
		A41 Jack Pine - Aspen / Bush Honeysuckle Forest	1	2518**	JPAX (shares)		
WF	WHITE SPRUCE - FIR FOREST	A42 Black Spruce / Feathermoss Forest	11	2447	BSF		
		A43 Spruce - Fir / Mountain Maple Forest	3	2446	SF		
		A44 Spruce - Fir - Aspen Forest	8	2475*	SFA		
AB	ASPEN - BIRCH FOREST	A45 Paper Birch / Fir Forest	1	2463	PB		
		A46 Aspen - Birch / Boreal Conifer Forest	4	2466*	AB (shares, JPAX & WRPA when mosaic)		
		A47 Aspen - Birch - Red Maple Forest	4	2467*	AB (shares, JPAX & WRPA when mosaic)		
NH	NORTHERN HARDWOODS (CONIFER) FOREST	A48 White Cedar - Yellow Birch Forest	4	2450	WCA		
		A49 Northern Bur Oak Mesic Forest	4	2072	BO		

roads, agricultural lands, quarries, streams and lakes (App. 2; see Anderson et al. 1976, Level II). Over 32 800 polygons were delimited. Maps and other documentation are available at <http://biology.usgs.gov/npsveg/voyal/>.

Finally, the organization of the map units was presented, not only by hierarchical order based on the US-NVC, whose upper levels are more applicable to global

vegetation patterns, but also by mid-scale ecological system (association-complex) relationships (Comer et al. 2003). These system relationships integrate the dynamic assemblages or complexes of plant communities that (1) occur together on the landscape; (2) are tied together by similar ecological processes, underlying abiotic environmental factors or gradients; and (3) form a readily

identifiable unit on the ground. The use of ecological systems emphasizes some of the ecological, rather than floristic or physiognomic, similarities among the types. For example, shrub bogs were grouped with treed bogs into a Bog System, whereas shrub poor fens were grouped with graminoid poor fens into a Poor Fen System.

#### *Accuracy assessment*

As recommended by the VMP in 1994, we assessed map accuracy using the standard confusion matrix approach, which indicates the percent of correctly and incorrectly mapped observations in binary form (Congalton 1991). More recently, fuzzy set theory has been used to provide a more ecologically realistic approach to assessing map accuracy (Gopal & Woodcock 1994; Townsend 2000). Here, we carefully inspected mapping errors, in order to determine the degree to which they were caused by confusion between closely related vegetation types.

Requirements for the VMP specify 80% accuracy for each map unit representing natural plant communities. Given the large number of map classes involved, and the financial constraints of the VMP, 80% accuracy is considered met if the estimated accuracy of a unit falls within the 90% confidence interval. The number of sites visited per map unit depended on how common the map unit was, from 30 polygons for widespread map units to five for rare map units.

Field test (validation) data were collected in 1997 and 1998. Polygons (and points within the polygons) were selected randomly within the three major areas (see Vegetation sampling above), but with logistic constraints. Accuracy assessment (AA) field crews navigated to the points using GPS PLGR (Precision Lightweight GPS Receiver, by Rockwell), which often have < 10 m or less error associated with the readings. Crews did not know the label of the polygon being visited. The AA crews assessed the plant community within a 0.5 h radius (the minimum mapping unit) and assigned a provisional community name using a classification key (Hop et al. 2001; see also Faber-Langendoen et al. in press). Dominant species by strata, environmental data (including topographic position, slope, and aspect), and rationale for classification were recorded, in part to help validate the field assignment. If known, the nearest plant communities were also recorded within 50 m of the point.

The test data (1251 plots) were entered into the PLOTS database, along with the assigned USNVC association code. For each data point, the field assigned association code was compared to the corresponding polygon map unit code. All mismatches were reviewed to see if there were any 'false errors', i.e., (1) GPS error, (2) test data point occurring in a zone of transition between two types (an ecotone), or (3) test data point

that was classified differently than the polygon but was clearly too small to map (an inclusion). Mismatches that were deemed 'false errors' were corrected, resulting in either a match or a true error. The corrected data were used to create a contingency table, or error matrix.

#### *Assessing rarity of plant community types*

The USNVC has become an important tool for assessing the relative rarity or extinction (extirpation) risk of associations, based on NatureServe methodology (Ambrose et al. 1994; Grossman et al. 1998; Regan et al. 2004). Each association has been assessed by NatureServe staff using 11 rank factors, which were integrated into an overall global rank. The ranks are assigned to each element on a 1-5 scale, G1 being critically imperiled on a global scale, G5 being globally secure and abundant (Regan et al. 2004).

#### *Vegetation response to major disturbances*

The Kabetogama Peninsula, the central 29 000 ha of land within the park (Fig. 1), was selected as the focus of the resource application of the vegetation map, because the history of forest disturbance, namely large-scale fires and logging, have been more adequately documented there than for other portions of the park. Park files show the extent of major fires in 1923 and 1936 and the extent of logging activities in the 1950s and 1960s, prior to park establishment. All polygons of fire and logging disturbance were delineated from various sets of aerial photography and transferred into Arc Info (Windels et al. in prep.). Current composition (percent area in fall of 1995) of the major upland forest types in each category (fire, logged, no disturbance) was summarized using the vegetation map.

## **Results and Discussion**

### *Vegetation classification*

The review and analysis of data from Voyageurs National Park and environs produced a list of 50 associations (Hop et al. 2001). Further analyses, summarized below, led to two new associations (Leatherleaf Poor Fen (A6) and Boreal Sedge Rich Fen (A10)), and deletion of three associations (Bog Birch - Leatherleaf Poor Fen, Black Spruce - Aspen Forest, and Balsam Fir - Paper Birch Forest (the latter two treated as phases of Spruce - Fir Aspen Forest)), for a final list of 49 associations and 42 alliances (Table 1). The number of alliances suggests that, for this project, there would have been little increase in map accuracy or reduction in effort gained by map-

ping at the alliance level since most alliances contain a single association within the study area. The 259 plots were each assigned to an association. Descriptions of each association are published in Hop et al. (2001) and Faber-Langendoen et al. (in press) (see example in App. 1, which includes the characteristic combination of species). Full association descriptions are also stored in the NatureServe (2006) database, and available at [www.natureserve.org/explorer/](http://www.natureserve.org/explorer/). Here we report their patterns on the ordinations.

### Wetland types

The initial ordination and cluster analyses suggested that the marsh communities (including both submerged and emergent aquatics) should be treated separately, and the 26 marsh plots were assigned to seven associations (Table 1, A24-A30). Multivariate analysis of the remaining 112 wetland plots showed two primary gradients, from open acid peatland to wet mineral forest along the first axis and forested acid peatland to wet meadow/shrub carr and shore fens along the second axis. Plots were assigned to 22 associations (Table 1, A1-A19, A21-23). Both DCA and NMS provided similar ordinations of the vegetation, though NMS explained a greater proportion of the variance (0.744 compared to 0.569) (Table 2). Overall rank order of the plots was similar between the two ordinations (Table 2). The summary matrix of the 22 associations was then analysed to determine if it effectively recovered the main gradients displayed by the plots. Visual inspection of the type ordination show associations of the same ecological system clustering together (Fig. 2). Correlations of structural and environmental patterns along the first two axes of the type ordination highlight the major gradients (Fig. 2, App. 2).

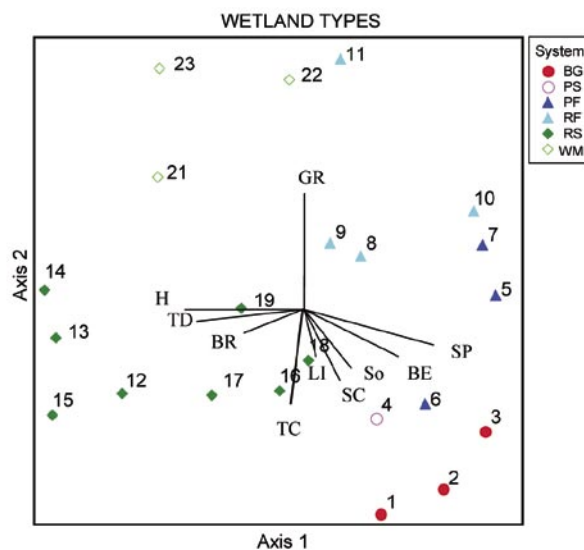
### Upland types

Multivariate analysis of the upland plots showed a strong gradient, from the wet minerotrophic forests to the dry rocky pine and oak woodlands, and a weaker secondary gradient from more conifer dominated moist black spruce/feathermoss forest to mesic upland hardwood forests. Although both DCA and NMS provided similar ordinations of the vegetation, NMS explained a greater proportion of the variance (0.747 compared to 0.530). Overall rank order of the plots was very similar between the two ordinations, especially on the first axis (Table 2). However, the first axis of DCA appeared to provide a more ecologically meaningful gradient. When the NMS ordination was rotated based on the soil depth categories, NMS plot scores then aligned in the same orientation as DCA scores. DCA is expected

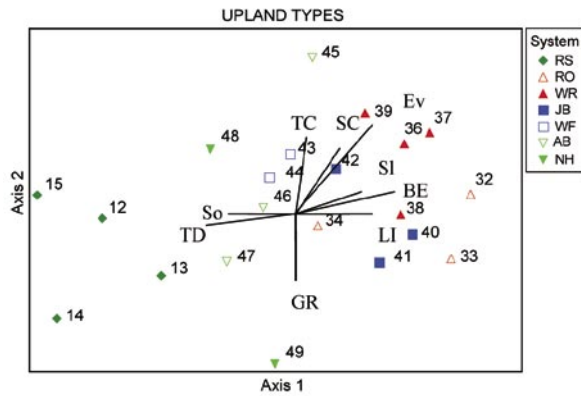
to handle strong unimodal gradients well (McCune & Grace 2002).

Upland plots were assigned to 21 associations (Table 1, A32-A34, A36-A49) and the types ordinated, as done for wetlands (Fig. 3). The jack pine/lichen rocky barrens (A31) and the boreal hazelnut – serviceberry rocky shrubland (A35) were outliers and removed from the final ordination, and type A35a, an uncommon and disturbed type, was only described from more qualitative field observations. Visual inspection of the type ordination show associations of the same ecological system clustering together, though not as cleanly as with the wetlands, mainly due to separations on the 2nd axis, and perhaps because of low plot counts for some of the types. However, the second axis also explains a much smaller proportion of the overall variance (Table 2). There were significant correlations of vegetation patterns to structural and environmental gradients (Fig. 3, App. 2). Table 3

The analysis of the plot data in large part corroborated the preliminary classification produced from other sources, based on sampling work at Voyageurs NP (Kurmis et al. 1986), from adjacent Ontario (Sims et al. 1989; Harris et al. 1996), and the Midwest vege-



**Fig. 2.** Distribution of wetland associations in NMS ordination space. Each point represents a single type, with the symbol representing the ecological system (Table 1). Line overlays indicate strength of environmental and structural correlations (App. 2). Axis 1 is related to a pH and saturation gradient from wet mineral soils dominated by rich hardwood swamps of broadleaf deciduous trees (TD), herbs (H), and *Bryales* mosses (BR) to bogs and poor fens, dominated by *Sphagnum* (SP) and broad-leaved evergreen (ericaceous) shrubs (BE). Axis 2 is related to decreasing deep-soil peats (So), tree and shrub conifers (TC, SC) and lichens of tree bogs and poor swamps to increasing graminoid (GR) dominance of rich fens and wet meadows.



**Fig. 3.** Distribution of upland associations in NMS ordination space. Each point represents a single type, with the symbol representing the ecological system (Table 1). Line overlays indicate strength of environmental and structural correlations (App. 2). Axis 1 is related to a soil moisture gradient of decreasing soil depth (So) and increasing slope (Sl) and elevation (Ev), and structural changes from broadleaf deciduous trees (TD) of rich hardwood swamps to increasing broadleaf evergreen (ericaceous) shrubs (BE) and lichens (LI) of rocky woodlands. Axis 2 is also related to increasing elevation (Ev) and increasing tree and shrub conifer (TC, SC) cover and decreasing graminoid (GR) cover between northern hardwoods and white pine-red pine systems.

tation classification (Faber-Langendoen 2001). It also suggested some important refinements, particularly in the open bedrock and the conifer swamp types. All changes to types were integrated into the USNVC and IVC (Anon. 2006).

**Table 2.** Summary of ordination characteristics for Detrended Correspondence Analysis (DCA) and Nonmetric Multidimensional Scaling (NMS). The R-Squared values ( $r^2$ ), or coefficient of determination, represents the proportion of variance explained by the ordination axes. Kendalls rank correlation  $\tau$  measures the correlation between DCA and NMS in the rank order of the stands along an axis. Ordinations were completed at both plot level and type (association) level (see Figs. 2 and 3 for type level ordinations).

	Plot level		$\tau$	Type level
	DCA $R^2$	NMS $R^2$		NMS $R^2$
<b>Wetlands</b>				
Axis 1	0.281	0.345	0.806	0.445
Axis 2	0.288	0.398	0.809	0.448
Total	0.569	0.744		0.893
<b>Uplands</b>				
Axis 1	0.373	0.58	0.907	0.78
Axis 2	0.157	0.167	0.761	0.135
Total	0.53	0.747		0.915

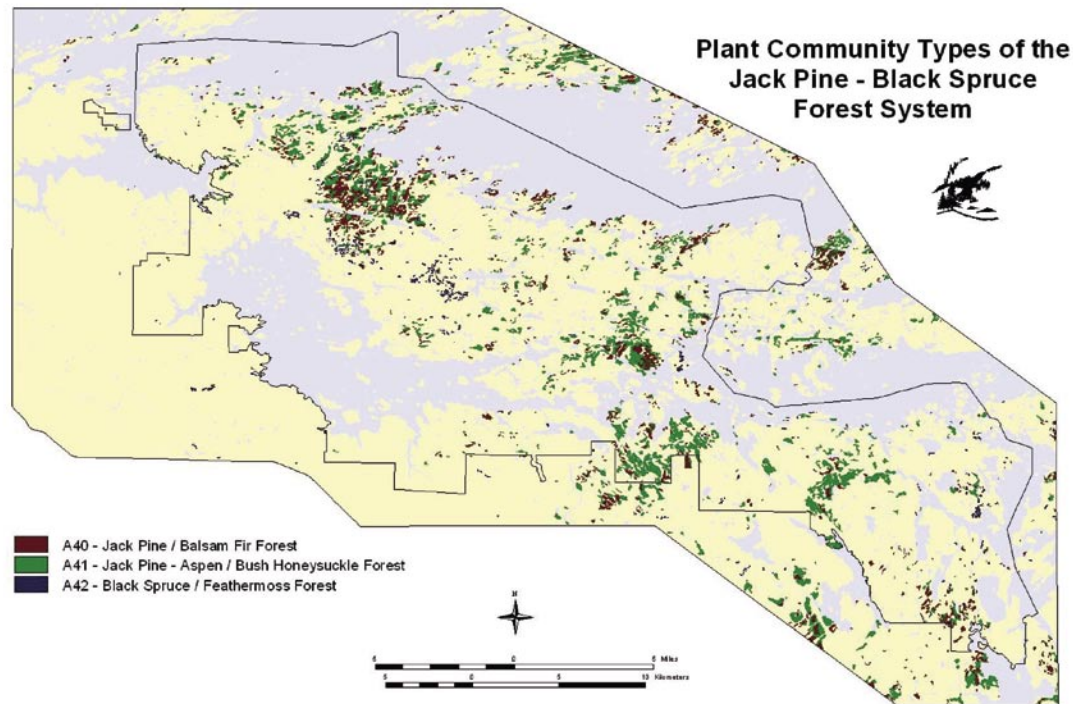
*Map units*

In total, 67 map units were used to map Voyageurs NP and environs (Table 1, App. 3; see Hop et al. 2001, App. F for more details); 50 of these map units represent vegetation types that belong to natural types, but the map units relate to the USNVC hierarchy at different levels. Forty-three of the 50 map units represent associations, or phases of associations. Three map units represent alliance-level units, and four map units represent *complexes* or *mosaics* that were created to handle vegetation patterns that were too complicated or intricate to map at the association or alliance levels (App. 3). Complexes are created when the individual communities are not recognizable on the aerial photographs but repeatedly occur together in the landscape. Mosaic map units are created when the individual communities are recognizable on the aerial photographs but occur in an intermixed pattern too intricate to map as separate polygons. For example, the Wet Meadow/Fen Mosaic/Complex Map Unit (SMX) includes five associations (A11, A22-A25): Canada Bluejoint Eastern Meadow, Northern Sedge Wet Meadow, Wiregrass Sedge Shore Fen, Eastern Reed Marsh, and Midwest Cattail Deep Marsh. One or more of these associations could occur in any given polygon designated as SMX. In addition, depending on the site, each association may be recognizable as an individual map unit (App. 3). From the perspective of the association units, 27 were uniquely mappable, 16 were both uniquely mappable and parts of mosaics/complexes, and 6 were always parts of mosaics/complexes (Table 1).

*Accuracy assessment*

A total of 41 map units and four ‘map unit groups’ were assessed for accuracy. The four map unit groups each contained units that represented phases of individual vegetation associations (e.g. the BSL evergreen phase and BST mixed phase of the Black Spruce / Labrador Tea Poor Swamp Association). We evaluated both producers’ accuracy (errors of omission), which is the probability that the map actually represents what was found on the ground, and users’ accuracy (errors of commission), which is the probability that a test data point has been mapped correctly.

The overall thematic accuracy was 82.4%. For producers’ accuracy, mean accuracy for 29 of the 45 units (64%) was at least 80%, and, for another 13 units, 80% fell within the 90% confidence interval, meaning that a total of 42 of the 45 units (93%) met the accuracy requirements. Three map units did not meet the Program’s goal for producers’ accuracy: the Quaking Aspen-Paper Birch Forest (AB, 65% with confidence interval 52-77%), the Spruce-Fir-Aspen Forest (SFA, 67% with confidence



**Fig. 4.** Map of Voyageurs National Park, showing distribution of map units / associations of the Jack Pine - Black Spruce Forest system (see also Table 1 and App. 3 for relation between associations and map units).

interval 54-79%), and the Northern Water Lily Aquatic Wetland (WL, 46% with confidence interval 31-61%).

For users' accuracy, mean accuracy for 30 of the 45 units (67%) was at least 80% accuracy, and, for another 14 units, 80% fell within the 90% confidence interval, meaning that a total of 44 of 45 units (98%) met the accuracy requirements. One map unit did not meet the Program's goal for users' accuracy: Midwest Pondweed Submerged Aquatic Wetland (PW, 44% with confidence interval 27-62%).

Inspection of the errors showed that most errors occurred between closely related types. Many of the errors were related to different estimates of percent cover between the photo-interpreter and ground crew. The photo-interpreter sees canopy crowns from the top-down at a relatively small scale but over a relatively large area, and the field crew sees the canopy from the bottom-up over a relatively small area. These different perspectives frequently lead to different estimates of percent cover, which in turn leads to differing conclusions on determining the vegetation type. This is particularly true for conical crowned species, whose canopy is often widest near the ground. For this reason, we rejected the option of combining map units that did not meet 80% accuracy; we felt it more useful to keep the map units separate and explain the errors rather than combine map units together. For example, producers' and users' accuracy

for the Trembling Aspen-Balsam Poplar Lowland Forest Map Unit (AL) fell below 80% because it was more difficult to map than expected. This map unit grades into the Quaking Aspen-Paper Birch Forest Map Unit (AB) and other upland forest map units with similar signatures. More than 3000 ha and >1000 polygons of AL have been mapped. Collapsing AL into AB would improve the accuracy assessment result, but the user would not know of the existence of AL, albeit with a lower degree of confidence. Alternatively, AL and AB could have been treated as map phases. Given that the primary sources of error appear to be related to confusion among closely related vegetation types, we are confident that our accuracy is quite high. In the future, applying a fuzzy approach to assessing mapped vegetation types (Townsend 2000) would allow us to more clearly portray these kinds of errors.

#### *Vegetation map*

A total area of 156 886 ha was mapped of Voyageurs National Park and environs, including a portion of Canada (Fig. 1). Of this total, natural/semi-natural vegetation represents about 101 652 ha, lakes and streams 53 445 ha, and small ponds 183 ha, indicating that almost all (99%) of the landscape is in natural condition (App. 3).

Attribute	Symbol	Axis 1			Axis 2		
		<i>r</i>	<i>r</i> <sup>2</sup>	$\tau$	<i>r</i>	<i>r</i> <sup>2</sup>	$\tau$
<b>WETLANDS</b>							
<b>Growth Form</b>							
Tree Conifer	TC	-0.190	0.036		<b>-0.673*</b>	0.453	
Shrub Conifer	SC	0.370	0.137		<b>-0.562*</b>	0.316	
Tree Deciduous	TD	<b>-0.716*</b>	0.512		-0.155	0.024	
Shrub Deciduous	SD	-0.212	0.045		-0.069	0.005	
Broad-leaved Evergreen	BE	<b>0.657*</b>	0.431		<b>-0.519*</b>	0.270	
Herbaceous	H	<b>-0.738*</b>	0.544		-0.114	0.013	
Graminoid	GR	0.019	0		<b>0.741*</b>	0.550	
Lichen	LI	0.234	0.055		<b>-0.465*</b>	0.216	
<i>Bryales</i>	BR	<b>-0.524*</b>	0.274		-0.349	0.122	
<i>Sphagnum</i>	SP	<b>0.763*</b>	0.583		<b>-0.473*</b>	0.223	
<b>Environmental</b>							
Slope	SI	-0.322	0.103		-0.153	0.023	
Aspect	As	0.430	0.185		0.152	0.023	
Elev	Ev	0.037	0.001		-0.148	0.022	
Soil depth	So			<b>0.329*</b>			-0.320
<b>UPLANDS</b>							
<b>Growth Form</b>							
Tree Conifer	TC	0.145	0.021		<b>0.498*</b>	0.248	
Shrub Conifer	SC	<b>0.451*</b>	0.204		<b>0.531*</b>	0.282	
Tree Deciduous	TD	<b>-0.625*</b>	0.390		-0.279	0.078	
Shrub Deciduous	SD	-0.131	0.017		0.011	0	
Broad-leaved Evergreen	BE	<b>0.609*</b>	0.371		0.249	0.062	
Herbaceous	H	-0.320	0.102		-0.411	0.169	
Graminoid	GR	-0.178	0.032		<b>-0.529*</b>	0.279	
Lichen	LI	<b>0.540*</b>	0.291		-0.018	0	
<i>Bryales</i>	BR	-0.239	0.057		0.183	0.034	
<i>Sphagnum</i>	SP	-0.305	0.093		-0.014	0	
<b>Environmental</b>							
Slope	SI	<b>0.508*</b>	0.258		0.255	0.065	
Aspect	As	0.262	0.068		0.117	0.014	
Elev	Ev	<b>0.559*</b>	0.313		<b>0.594*</b>	0.352	
Soil depth	So			<b>-0.381*</b>			-0.005

**Table 3.** Correlations between NMS ordination axes and environmental-structural attributes of the 21 upland and 22 wetland associations (see Figs. 2 and 3). Pearson’s *r* and *r*<sup>2</sup> are reported for all attributes except for soil depth (a categorical variable), where Kendall’s  $\tau$  coefficient is reported. All structural growth form attributes measure the percent cover of a given growth form. Significance is reported as \* = *p* < 0.05.

Vegetation units with the greatest total area include the Quaking Aspen-Paper Birch Forest (> 21 000 ha, AB, alliance), the Spruce Fir-Aspen Forest (> 12 000 ha, SFA, alliance), the White Pine-Red Pine-Quaking Aspen-Paper Birch Forest (> 9500 ha, WRPA, alliance / mosaic), and the Jack Pine - Aspen Forest (> 4500 ha, JPAX, alliance / mosaic) (App. 3). These map units belong to four different ecological systems: Aspen-Birch Forest, White Spruce-Fir Forest, Northern Pine - Oak Forest, and Jack Pine - Black Spruce Forest. The most extensive wetland units are Black Spruce / Labrador Tea Poor Swamp (> 3800 ha) and Wet Meadow / Fen Mosaic / Complex (> 4400 ha).

The map units with the largest polygon areas are in the Rat Root River Peatland: Black Spruce Bog (BSB) and Tamarack Scrub Poor Fen (TS) (App. 3). Although few in number (25 and 9 polygons respectively) these polygons range from an average of > 30 ha for BSB to 19 ha for TF. Average polygon size drops sharply, to 9 ha or less for all other vegetated map units. The Rat Root River peatland, found mostly outside the park boundaries (Fig. 1), is a striking feature of this sub-boreal landscape.

Of the 32 841 polygons, the highest number (> 5500)

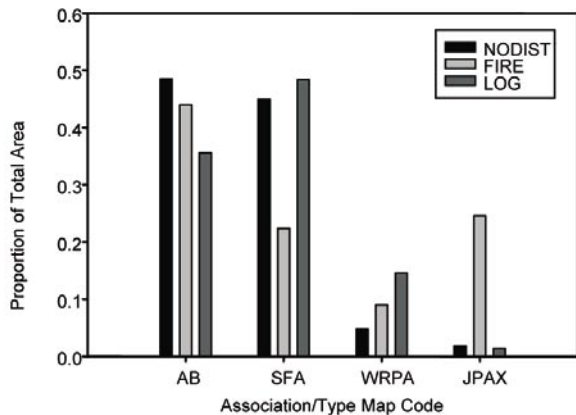
is assigned to the Rocky Outcrop / Woodland system (App. 3). The associations recognized by these map units (A31-A35, Table 1) are confined to ridge tops and slopes with thin soils and exposed bedrock.

Relatively rare in both number of polygons and in area are the map units Paper Birch/Fir Forest (PB) and Northern Bur Oak Mesic Forest (BO). PB occurs only near Deer Point Islands in the park. BO is most common on islands and peninsulas of Kabetogama Lake.

Each of the natural / semi-natural map units was grouped into the ecological system to which it belonged, and the distribution and extent of both the system and component associations are displayable across the park using digital mapping tools (Fig. 4).

#### *Vegetation response to major disturbances in the Kabetogama Peninsula*

Based on historic records and maps of the Kabetogama Peninsula, the following kinds of major disturbances covered the area; (1) fire ca. 17 086 ha (60%), (2) logging ca. 2036 ha (7%), (3) no fire or logging ca. 9538 ha (33%). The disturbance type affected relative composition



**Fig. 5.** Response of four major forest associations to fire and logging disturbances on the Kabetogama Peninsula, Voyageurs National Park, MN. Graph shows the areal proportion of each type found in each of the three disturbance categories, i.e. values for all four associations will sum to 1.0 within each disturbance type. See Table 1 for full name of association/type map code.

of the four forest types we assessed. Area of Jack Pine – Aspen Forest Mosaic (JPAX), as a proportion of total area within a disturbance type, was greatest for burned areas, as expected (Fig. 5). Proportion of total area for Quaking Aspen–Paper Birch (AB) and White Pine – Red Pine – Quaking Aspen – Paper Birch Forest (WRPA) was relatively similar among disturbance types, whereas proportion of total area for Spruce - Fir - Aspen Forest (SFA) was markedly lowest in the burned areas compared to logged and undisturbed areas. Overall, the least fire tolerant association map units (AB and SFA) dominate the peninsula, whereas the fire dependent associations have declined. Lack of current large, scale fires appears to be reducing the percentage of jack pine types on the landscape. White pine and red pine stands are currently so low in abundance that their response to major disturbances is hard to assess.

#### *Rarity of plant community types*

The rarity (risk of extirpation) rank assigned by NatureServe to the 49 associations listed for Voyageurs, shows that only three types are somewhat vulnerable –the Red Pine / Blueberry Dry Forest (A36), G3, the Northern Sedge Poor Fen (A7), G3G4 and the White Pine / Mountain Maple Mesic Forest (A39), G3G4; all the rest were ranked as G4 or G5. Global vulnerability of the two forest types highlights their decline across their range, and the need for restoration management of these types at Voyageurs NP.

#### **Conclusion**

Overall, the Voyageurs NP maps based on the USNVC classification, provide resource managers, conservationists and researchers with valuable information on the extent and patterning of the vegetation, at a scale of resolution where individual association patterns are often visible. The scale of the map provides a baseline for assessing the effects of past and future disturbances. Managers can now apply rigorous analyses to assess their management goals, such as assessing and monitoring the effects of past and ongoing fire management. Other applications under way at Voyageurs NP include establishing wildlife surveys, in which the map was used to ensure that transects bisect the major habitats in the park, and assessing the relation of park ecosystems to activities in the mapped buffer areas.

Integration of the USNVC with the IVC provides a global perspective on those plant communities found in the park that may be most vulnerable, based on cross-jurisdictional comparisons of where these communities are, and what their conservation status is. National parks across the country can be compared not just to each other (such as between Voyageurs NP and Isle Royale NP, two boreal parks in the upper Midwestern U.S.), but to information collected on state and other federal lands, when that information is also based on or linked to the NVC. This partnership is demonstrated through the work of the Minnesota County Biological Survey and Natural Heritage and Nongame Research Programs, which maintain information on natural plant communities across the state, and link their classification to the USNVC. This linkage allows Voyageurs NP staff to understand how their resources contribute to the overall protection of the state's resources. In turn, park resources can be put in a global context through use of the International Vegetation Classification, because of the ongoing collaborations between U.S. and Canadian vegetation classifications (Alvo & Ponomarenko 2003; Jennings et al. 2004).

Mapping the parks at the association or alliance level and portraying these patterns based on the ecological systems approach (Fig. 4) provides an important complement to the use of the USNVC hierarchy alone, at least in its current form. Recent proposed revisions to the hierarchy will include more floristic-ecologically meaningful units above the alliance. Ecological systems emphasize the ecological processes and spatial, rather than taxonomic, relations of the associations and alliances, and this may be more appropriate for some objectives. For example, when developing monitoring protocols for park resources, sampling schemes that consider both vegetation and ecological processes leads to more robust methods, since monitoring needs to detect changes to both aspects of the resource (Mitchell et al. 2006).

We highly recommend that a completed (or nearly completed) classification be in place before the actual photo-interpretation begins. Classification plot sampling should begin early in the project, followed by analysis of the vegetation data before the mappers begin their work. Mappers should have a vegetation key and written descriptions of the associations during reconnaissance so they can determine what the specific type is on the ground and what its photo signatures might be. Ideally, mappers and ecologists should do field reconnaissance together so that a strong connection between mapping and classification is created from the beginning of the project. The purpose of using the USNVC as a standard is to promote increased sharing, exchanging, and comparing of vegetation-related data among federal government agencies and other partners, and this is greatly hindered when map units deviate from that standard.

Better methodologies for assessing map accuracy should be considered, based on fuzzy set theory (Gopal & Woodcock 1994; Townsend 2000). This may require that field data collection for test (AA) plots be somewhat more standardized (e.g., listing all plants exceeding a percent cover threshold (e.g., 5%), in order that these test plots can be compared to reference classification type descriptions (see Townsend 2000 for details). Fuzzy approaches allow users to better understand the underlying ecological relationships among map classes and potentially valid reasons for mapping errors.

The final map products at Voyageurs NP represent an important and successful test of the ability of the USNVC to describe the natural variability of the park ecosystems. Although these classification and mapping tools come from an older and ongoing tradition, they have been incorporated into a new approach used by the USGS-NPS VMP, and provide an integrated set of new products. Use of digital mapping tools, and publicly available archives and databases, such as NatureServe Explorer and VegBank, continue to make the information widely available to vegetation ecologists, resource managers, and others.

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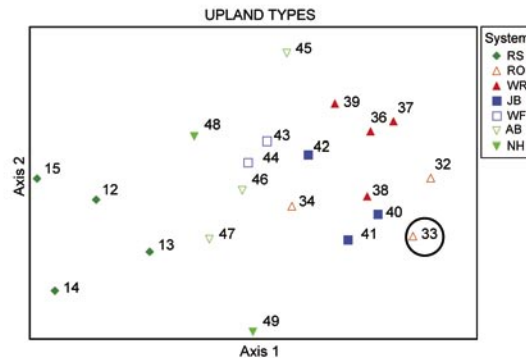
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For Apps. 1-2, see *JVS/AVS Electronic Archives*;  
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## App. 1. Example of association description.

A33

**Northern Pin Oak - Bur Oak - (Jack Pine) Rocky Woodland***Quercus ellipsoidalis* - *Quercus macrocarpa* - (*Pinus banksiana*) Rocky Woodland

## Description

This community is characterized by either a canopy dominated by northern pin oak, with occasional bur oak or jack pine, or with large jack pine, red pine or white pine either forming an emergent canopy over the oak trees, or mixed with the oaks. This type varies from pure deciduous to mixed evergreen-deciduous. Stands may also vary in canopy cover from 30% (“woodland” physiognomy) to 90% (“forest” physiognomy), and the canopy may barely exceed 5 m, creating a scrub woodland appearance. Open bedrock ridges with oak may be found in a mosaic with more closed oak stands. The shrub layer may have 20-40% cover, with *Corylus cornuta* (beaked hazelnut), *Viburnum rafinesquianum* (downy arrow-wood), northern pin oak, and *Amelanchier* spp. (serviceberry) most abundant. *Vaccinium angustifolium* (lowbush blueberry) is the most common dwarf-shrub; others include *Juniperus communis* (common juniper), *Prunus pumila* (sand cherry), *Arctostaphylos uva-ursi* (bearberry), and *Comptonia peregrina* (sweet fern). Cover of the herbaceous layer is highly variable, ranging from 20-80%, with the most abundant herbs being *Aralia nudicaulis* (wild sarsaparilla), *Aster macrophyllus* (large-leaved aster), *Fragaria virginiana* (common strawberry), *Maianthemum canadense* (canada mayflower), *Pteridium aquilinum* (bracken), *Danthonia spicata* (poverty grass), and *Oryzopsis asperifolia* (mountain rice-grass). The moss-lichen layer can be absent or present with up to 30% cover. In the open bedrock areas this layer consists mainly of the lichens *Cladina rangiferina*, *Cladina mitis*, *Cladina stellaris*, and, to a lesser degree, the mosses *Polytrichum juniperinum*, *Polytrichum piliferum*, *Hedwigia ciliata*, and *Orthotrichum* spp. Under the canopy of oaks, the moss-lichen layer consists primarily of *Pleurozium schreberi* and *Dicranum* spp.

This type occurs on ridge tops and high slopes, and some dry, flat, rocky areas. Slopes range from 0-20% with variable aspects. These sites are generally dry, well drained sites with exposed bedrock typical in the more open stands and commonly covering 10-30% of the ground. In some stands, exposed bedrock may be absent. In both cases, soils are fairly rocky, shallow loams, averaging 3-5 cm deep.

CONSERVATION RANK G?

DATABASE CODE C EGL005246

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**ROCKY OUTCROP / WOODLAND**

**CHARACTERISTIC SPECIES** ( $n = 16$  plots, 66 observation points) (constancy =I-V; cover=1-100%),

**Shrub/Scrub**

*Abies balsamea* (balsam fir) III.4, *Acer rubrum* (red maple) V.7, *Amelanchier* spec. (serviceberry) V.7, *Betula papyrifera* (paper birch) V.1, *Corylus cornuta* (beaked hazelnut) IV.4, *Pinus strobus* (white pine) V.4, *Quercus ellipsoidal* (northern pin oak) V.45, *Viburnum rafinesquianum* (downy arrow-wood) III.4

**Dwarf-shrub**

*Comptonia peregrina* (sweet fern) III.4, *Diervilla lonicera* (bush honeysuckle) IV.2, *Gaultheria procumbens* (wintergreen) IV.2, *Rosa blanda* (and others) (rose) V.1, *Rubus strigosus* (red raspberry) IV.1, *Vaccinium angustifolium* (lowbush blueberry) V.15

**Forb**

*Aralia nudicaulis* (wild sarsaparilla) V.7, *Aster macrophyllus* (large-leaved aster) V.15, *Fragaria virginiana* (common strawberry) IV.1, *Maianthemum canadense* (canada mayflower) V.2, *Pteridium aquilinum* (bracken) V.15

**Graminoid**

*Danthonia spicata* (poverty grass) V.15, *Oryzopsis asperifolia* (mountain rice-grass) V.7

**RANGE**

*Voyageurs National Park*

This type occurs on ridge tops and high slopes throughout the park.

*Global*

This association is found in northern Minnesota, Ontario, and Manitoba.

**COMMENTS**

Diagnostic features of the type include the forest or woodland canopy consisting primarily of northern pin oak, with varying amounts of bur oak, jack pine, red pine, and white pine, and a rocky substrate, with dry herbaceous, moss, and lichen species. Though there are some differences, quantitative analysis indicates that the floristic similarities between the oak woodland and the oak forest warrant including them as open and closed version of the same type. This type lacks balsam fir, whereas the Boreal Pine Rocky Woodland (A32) usually contains it. Stands of this type on Dryweed Island appear to be distinct from the stands that occur in the rest of the park, presumably because of the differences in underlying greenstone bedrock. This type includes only those bur oak stands with exposed bedrock and woodland physiognomy. Forested mesic situations with bur oak are included in the Northern Bur Oak Mesic Forest (A49). The type is most similar to Ontario's V3.3 (Sims et al. 1997).

**MAP UNITS**

Northern Pin Oak-Bur Oak -(Jack Pine) Rocky Woodland (deciduous phase) (OW) & (jack pine-oak phase) (JPOM), and Northern Pin Oak-Bur Oak-(Jack Pine) Rocky Woodland (mixed pine-oak phase) (MPHW).

**MINNESOTA STATE TYPE 2003 (MN DNR 2003)**

Pin Oak Woodland (Bedrock) (FDn22c)

**App. 2.** Summary of map units, names, and number of polygons and area for Voyageurs National Park. The link between Map Unit Names and associations is provided in Table 1. \* = Map units at alliance level. \*\* = Map units at complex / mosaic level. Other map units are at association or finer level.

Map Unit Code	Map Unit Name	No. of Polygons	Hectares	Avg (ha)	Acres	Avg (ac)
<b>Natural/Semi-natural Vegetation Map Units</b>						
<b>Bog</b>						
BSB	Black Spruce Bog	25	761	30	1879	75
LBC	Black Spruce/Leatherleaf Semi-treed Bog	212	1703	8	4208	20
LB	Leatherleaf Bog	297	892	3	2205	7
BBX **	Beaver Basin Break-up Mosaic	29	71	2	176	6
<b>Poor Swamp</b>						
BSL	Black Spruce/Labrador Tea Poor Swamp (evergreen phase)	704	2937	4	7257	10
BST	Black Spruce/Labrador Tea Poor Swamp (mixed phase)	224	938	4	2318	10
<b>Poor Fen</b>						
TF	Tamarack Scrub Poor Fen	9	172	19	425	47
SPF	Northern Sedge Poor Fen	8	65	8	161	20
<b>Rich Fen</b>						
BBSF	Bog Birch-Willow Shore Fen	51	238	5	588	12
LSF	Leatherleaf-Sweet Gale Shore Fen	134	464	3	1146	9
<b>Rich Swamp</b>						
BA	Black Ash-Mixed Hardwood Swamp	1586	2677	2	6616	4
WCBA	White Cedar-Black Ash Swamp	272	829	3	2049	8
BSAS	Black Spruce/Alder Rich Swamp	536	707	1	1748	3
TA	Northern Tamarack Rich Swamp	255	705	3	1743	7
WCS	White Cedar-(Mixed Conifer)/Alder Swamp (rich soil phase)	214	1011	5	2499	12
WCT	White Cedar-(Mixed Conifer)/Alder Swamp (peatland phase)	24	64	3	158	7
WCU	White Cedar-Boreal Conifer Mesic Forest	324	488	2	1207	4
AL	Trembling Aspen-Balsam Poplar Lowland Forest	1261	3155	3	7797	6
<b>Wet Meadow – Shrub Swamp</b>						
BJ	Canada Bluejoint Eastern Meadow	475	752	2	1858	4
DS	Dogwood-Pussy Willow Swamp	262	587	2	1450	6
AS	Speckled Alder Swamp	1595	2825	2	6981	4
SMX **	Wet Meadow/Fen Mosaic/Complex	2012	4484	2	11080	6
<b>Freshwater Marsh</b>						
PM	Eastern Reed Marsh	8	4	0	9	1
BM	Freshwater Bulrush Marsh	6	7	1	18	3
CM	Midwest Cattail Deep Marsh	212	475	2	1173	6
WRM	Wild Rice Marsh	38	267	7	661	17
DMX **	Deep Marsh Mosaic/Complex	959	1852	2	4575	5
PW	Midwest Pondweed Submerged Aquatic Wetland	669	1223	2	3023	5
WL	Northern Water Lily Aquatic Wetland	450	979	2	2418	5
<b>Rocky Outcrop / Woodland</b>						
JPW	Boreal Pine Rocky Woodland (jack pine phase)	1087	2118	2	5233	5
JPM	Boreal Pine Rocky Woodland (mixed pine phase)	1774	3351	2	8280	5
JPL	Jack Pine/Lichen Rocky Barrens	57	84	1	208	4
ABW	Mixed Aspen Rocky Woodland	856	1659	2	4099	5
OW	Northern Pin Oak-Bur Oak-(Jack Pine) Rocky Woodland (deciduous phase)	303	827	3	2044	7
JPOM	Northern Pin Oak-Bur Oak-(Jack Pine) Rocky Woodland (jack pine-oak phase)	34	77	2	190	6
MPHW	Northern Pin Oak-Bur Oak-(Jack Pine) Rocky Woodland (mixed pine-oak phase)	1472	3713	3	9176	6
UBS	Boreal Hazelnut-Serviceberry Rocky Shrubland	598	1518	3	3750	6
MGF	Poverty Grass Granite Barrens	113	116	1	286	3
<b>Northern Pine (White Pine, Red Pine) – Oak Forest</b>						
WRPA **	White Pine-Red Pine-Quaking Aspen-Paper Birch Forest	1486	9823	7	24 274	16
RP	Red Pine/Blueberry Dry Forest	289	594	2	1468	5
WP	White Pine/Mountain Maple Mesic Forest	645	1728	3	4271	7

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## App. 2, cont.

Map Unit Code	Map Unit Name	No.of Polygons	Hectares	Avg (ha)	Acres	Avg (ac)
<b>Natural/Semi-natural Vegetation Map Units</b>						
<b>Jack Pine – Black Spruce Forest</b>						
JPAX **	Jack Pine-Aspen Forest Mosaic	715	4592	6	11 348	16
JPF	Jack Pine/Balsam Fir Forest	909	2502	3	6183	7
BSF	Black Spruce/Feathermoss Forest	406	551	1	1360	3
<b>White Spruce-Fir Forest</b>						
SFA *	Spruce-Fir-Aspen Forest	2649	12 225	5	30209	11
SF	Spruce-Fir/Mountain Maple Forest	1167	1958	2	4838	4
<b>Aspen – Birch Forest</b>						
AB *	Quaking Aspen-Paper Birch Forest	3361	21 696	6	53613	16
PB	Paper Birch/Fir Forest	4	21	5	52	13
<b>Northern Hardwood – (Conifer) Forest</b>						
WCA	White Cedar-Yellow Birch Forest	384	1,010	3	2,496	6
BO	Northern Bur Oak Mesic Forest	83	156	2	384	5
<b>Planted/Cultivated, Land Use/Land Cover, and Park Specific Map Units</b>						
<b>Planted/Cultivated Vegetation (USNVC)</b>						
EP	Evergreen Plantation	88	318	4	786	9
PGCH	Perennial Grass Crops (hay, pastureland)	4	4	1	10	2
PGCS	Perennial Grass Crops with Sparse Shrubs (hay, pastureland)	39	164	4	406	10
		45	150	3	370	8
<b>Land Use/Land Cover (USGS - Anderson Level II)</b>						
<b>Developed Lands</b>						
ACP	Cropland and Pasture	385	54559	142	134819	350
ARB	Other Agricultural Land	335	1115	3	2755	8
BLQ	Strip Mines, Quarries, and Gravel Pits	31	200	6	494	16
UC	Commercial and Services	58	78	1	192	3
UR	Residential	16	74	5	184	11
UT	Transportation, Communications, and Utilities	47	210	4	519	11
		179	269	2	664	4
		4	284	71	702	175
<b>Lakes and Streams</b>						
WLK	Lakes (>16 h)	50	53445	1069	132064	2641
WS	Streams and Canals	40	53347	1334	131824	3296
		10	97	10	240	24
<b>Small Islands and Natural Ponds (Park Specific)</b>						
SIG	Small Island with Grass	1125	357	0	882	1
SIR	Small Island with Rock	11	1	0	3	0
SIS	Small Island with Shrubs	58	6	0	14	0
SIT	Small Island with Trees	128	16	0	39	0
WBP*	Water-Beaver Pond	855	152	0	375	0
WNP	Water-Natural Pond (<16 h)	52	70	1	173	3
		21	113	5	279	13
<b>Totals</b>						
All Map Units		32 841	156886	5	387674	12
Natural/Semi-natural Vegetation Map Units		31243	101652	3	251187	8
Planted/Cultivated, Land Use/Land Cover, and Park Specific Map Units		1598	55234	35	136487	85

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**Plate A1.** *Pinus banksiana* - (*Picea mariana*, *Pinus strobus*) / *Vaccinium* spp.  
 Rocky Woodland  
 Boreal Pine Rocky Woodland  
 Along Blind Ash Bay Trail, Voyageurs National Park, Minne-



**Plate A2.** *Picea mariana* / *Chamaedaphne calyculata* / *Sphagnum* spp. Dwarf-shrubland  
 Black Spruce / Leatherleaf Semi-treed Bog  
 Large peatland complex between Black Bay and Cranberry Bay, Voyageurs National Park, Minnesota

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**Plate A3.** White Spruce - Balsam Fir (*Picea glauca* - *Abies balsamea*) forests and White Pine (*Pinus strobus*) stands with Canada bluejoint (*Calamagrostis canadensis*) meadows along shore, and submergent vegetation in the stream. Near Cranberry Creek Campsite, Voyageurs National Park, Minnesota