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Revised Vegetation Classification for Mount Rainier, North Cascades, and Olympic National Parks

Project Summary Report

Natural Resource Report NPS/NCCN/NRR—2021/2225

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ON THIS PAGE

The sun rises on a *Carex spectabilis* - *Polygonum bistortoides* Alpine Meadow in Fisher Basin, North Cascades National Park
Photograph by Tynan Ramm-Granberg

ON THE COVER

Clockwise from upper left: 1) A matrix of non-vegetated land cover (glaciers, scree, etc.), alpine turf communities, subalpine woodlands, mesic herbaceous meadows, and high elevation wetlands on the north face of Mount Rainier; 2) *Carex utriculata* Montane Marsh along the Chilliwack River at North Cascades National Park; 3) *Carex nigricans* - (*Petasites frigidus* var. *frigidus*) / *Philonotis fontana* Seep in Spray Park at Mount Rainier National Park; 4) *Pseudotsuga menziesii* - *Tsuga heterophylla* / *Mahonia nervosa* Forest near Royal Basin at Olympic National Park.
Photographs by Tynan Ramm-Granberg

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This report received formal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data. Data in this report were collected and analyzed using methods based on established, peer-reviewed protocols and were analyzed and interpreted within the guidelines of the Inventory and Monitoring Program.

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Executive Summary

Field crews recently collected more than 10 years of classification and mapping data in support of the North Coast and Cascades Inventory and Monitoring Network (NCCN) vegetation maps of Mount Rainier (MORA), Olympic (OLYM), and North Cascades (NOCA) National Parks. Synthesis and analysis of these 6000+ plots by Washington Natural Heritage Program (WNHP) and Institute for Natural Resources (INR) staff built on the foundation provided by the earlier classification work of Crawford et al. (2009). These analyses provided support for most of the provisional plant associations in Crawford et al. (2009), while also revealing previously undescribed vegetation types that were not represented in the United States National Vegetation Classification (USNVC). Both provisional and undescribed types have since been submitted to the USNVC by WNHP staff through a peer-reviewed process.

NCCN plots were combined with statewide forest and wetland plot data from the US Forest Service (USFS) and other sources to create a comprehensive data set for Washington. Analyses incorporated Cluster Analysis, Nonmetric Multidimensional Scaling (NMS), Multi-Response Permutation Procedure (MRPP), and Indicator Species Analysis (ISA) to identify, vet, and describe USNVC group, alliance, and association distinctions. The resulting revised classification contains 321 plant associations in 99 alliances. A total of 54 upland associations were moved through the peer review process and are now part of the USNVC. Of those, 45 were provisional or preliminary types from Crawford et al. (2009), with 9 additional new associations that were originally identified by INR. WNHP also revised the concepts of 34 associations, wrote descriptions for 2 existing associations, eliminated/archived 2 associations, and created 4 new upland alliances. Finally, WNHP created 27 new wetland alliances and revised or clarified an additional 21 as part of this project (not all of those occur in the parks).

This report and accompanying vegetation descriptions, keys and synoptic and environmental tables (all products available from the NPS Data Store project reference: https://irma.nps.gov/DataStore/Reference/Profile/2279907) present the fruit of these combined efforts: a comprehensive, up-to-date vegetation classification for the three major national parks of Washington State.

Acknowledgments

This project builds upon the classification work of Crawford et al. (Crawford et al., 2009). The National Park Service (NPS) North Coast and Cascades Network (NCCN) Inventory and Monitoring program provided funding for this project. NatureServe senior ecologists M. Reid (retired), P. McIntyre, and D. Faber-Langendoen provided USNVC resources and oversaw the peer review process. Special thanks go to the field staff that collected the data, under frequently challenging conditions: N. Anderson, W. Arneson, P. Barnes, C. Batey, W. Bennett, T. Brussel, R. Bryson, E. Burke, W. Clark, I. Cunningham, D. Risako, J. deGuzman, P. Del Zotto, E. Derickson, C. Duncan, H. Faulstich, A. Francis, D. Graham, L. Graham, R. Gwodz, M. Hansen, E. Hegarty, T. Hender, M.Hiramatsu, M. Imman, S. Johnson, S. Kast, E. Keena-Levin, S. Koenig, E. Kohler, M. Lee, S. McDonough, C. Meredith, C. Meston, T. Morrison, L. Moulton, A. Nabors, A. Nemeth, K. O'Neil, G. Pappas, R. Peace, A. Peterson, E. Pruiksma, E. Raimundo, J. Runge, C. Schmidt, J. Smith, S. Stowell, A. Tyson, J. Waite, B. Wallace, D. Wallace-Senft, M. Whisman, and L. Wise.

Acronyms

DBH - Diameter at Breast Height

EPA - Environmental Protection Agency

INR - Institute for Natural Resources

MMU - Minimum Mapping Unit

MORA - Mount Rainier National Park

NCCN - North Coast and Cascades Network

NOCA - North Cascades National Park

NPS - National Park Service

NVC - National Vegetation Classification

OLYM - Olympic National Park

SCAM - Species Cover - Association Match Tool

USNVC - United States National Vegetation Classification

WNHP - Washington Natural Heritage Program

Introduction

Plant communities can be described by patterns of species composition, structure, and/or growth forms related to underlying ecological processes and environmental variables (United States National Vegetation Classification 2019). The USNVC was created in order to provide a common language for land management and conservation of these plant communities across the diverse landscapes of the United States (Federal Geographic Data Committee 2008; Faber-Langendoen et al. 2016). The USNVC is a hierarchical classification, with higher levels defined by broad growth form categories and global macroclimate factors, middle levels incorporating additional physiognomic, biogeographic, and broad floristic factors, and lower levels defined by increasingly narrow similarities in floristic composition (Franklin et al. 2012).

Following Federal Geographic Data Committee standards, NPS Inventory & Monitoring Networks use the USNVC as the basis for their vegetation maps. Vegetation mapping is a critical element of NPS efforts to understand the range and long-term trends of natural resources in and around parks (National Park Service 2018). In Washington State, the NPS is in the final stages of a project to develop vegetation maps for all of the park units in the North Coast and Cascades Network (NCCN). This network includes Mount Rainier (MORA) and Olympic (OLYM) National Parks, as well as the North Cascades National Park Complex (NOCA). These large wilderness parks contain a wide range of vegetation types, from bogs to high-quality conifer forests to alpine habitats. The first phase of mapping work in the NCCN described and classified these varied vegetation types using the USNVC. NCCN collaborated with the Washington Department of Natural Resources Natural Heritage Program (WNHP) to produce an association-level classification for the three wilderness parks, culminating in a plot- and literature-based report (Crawford et al., 2009) consisting of 375 upland and wetland plant associations. This included 171 provisional/preliminary types not yet recognized in the nationwide USNVC.

The classification guided field data collection and provided descriptions of vegetation types that the mapping technical team (Institute for Natural Resources, INR) later combined into coarser map classes. During training data collection, field crews encountered previously under-sampled plant communities and types undocumented in Crawford et al. (2009). INR's comprehensive review of the training plot data identified additional new associations not recognized in the USNVC (or Crawford et al. 2009), as well as modifications to existing USNVC association concepts (such as changes to the geographic range or floristic composition). INR also identified problematic sections of the field key and association descriptions that may have led to inconsistent data. WNHP reviewed INR's proposed associations, provided region-wide context, and advanced proposed changes through a peer-review process and into the USNVC. For wetland types, WNHP focused on revising USNVC groups and alliances (higher levels of the hierarchy). This document and its accompanying descriptions, keys and tables (Ramm-Granberg 2021a) represents an update of Crawford et al. (2009), promoting maximum congruence between the final mapping products and the vegetation classification.

Methods

2009 Classification Phase

Initial Sampling Method

Classification fieldwork began in 2005, focusing on known gaps in "legacy" data sets (see Crawford et al. 2009, Appendix E) from existing regional vegetation classifications. Sampling methodology combined guidance from the NPS Field Methods for Vegetation Mapping (The Nature Conservancy & Environmental Systems Institute Inc. 1994), WNHP protocols, and USFS methods (Henderson & Lesher 2003). Field crews established fixed-radius plots in patches of homogeneous vegetation, with size dependent on vegetation structure. Forested plots were 400 m^2, shrublands were 100 m^2, and dwarf-shrub, herbaceous, and sparsely vegetated plots were 50 m^2. Within each plot, crews collected environmental data, including aspect, slope, elevation, landform, microposition, macroposition, apparent hydrologic regime, and topographic moisture (a moisture availability index that relates concavity/convexity at the plot scale to relative slope position) (Henderson & Lesher 2003). Crews dug a shallow hole at each site in order to characterize the soil, recording the texture and color of each horizon.

Field staff characterized the vegetation at each plot by recording the physiognomic class (forested, shrubland, etc.), dominant leaf-type (coniferous/deciduous), and the cover of dominant species (for each stratum). When possible, association descriptions and keys were used to assign an association call and, if not, a preliminary name for the undescribed type was recorded. Crews collected full ocular species lists, including canopy cover (in classes). Ground stratum bryophyte species were recorded when their cover exceeded 1%, but those growing on logs were excluded.

Initial Analysis and Plot Assignment to Types

Crawford et al. (2009) evaluated 3396 plots and assigned these to 375 association concepts. The data set consisted of 917 new NPS classification plots and 2479 "legacy" plots pulled from historical data sets (Table 1). All legacy data sets used in the classification were required to have near-complete vascular species lists, with cover values and plot sizes that scaled with different vegetation types (e.g. larger plots in forests) (Crawford et al. 2009). Of the 375 association concepts in Crawford et al. (2009), 171 were accepted in the USNVC as of 2019 (hierarchy 36, USNVC v2.03), while 204 remained as preliminary/provisional associations. Plot data were managed in VPRO, a Microsoft Access-based program developed and managed by the British Columbia Ministry of Forests Research Branch (Mackenzie & Klassen 1999).

Table 1. Legacy plot data used in Crawford et al (2009). This does not contain legacy data sets that were evaluated, but failed to meet minimum criteria for the classification.

Park	Project Name / Principal Investigator	Reference
MORA	Edward's Mt Rainier Vegetation Plots	G. Rochefort, NPS, Unpublished Data
	Hamann Thesis	Hamann (1972)
	Franklin	Franklin et al. (1988)
OLYM	Belsky	Belsky & Del Moral (1982)
	Goat Reconnaissance Plots	Houston et al. (1994)
	Woodward LTEM Vegetation Survey - Elwha River	A. Woodward, USGS, Unpublished Data
	Kunze Wetland Classifications	Kunze (1989, 1990, 1991, 1994)
	Henderson - USFS Classification	Henderson et al. (1979)

Plots not clearly assignable to preexisting types from the literature and/or USNVC were analyzed using the following procedure (adapted from Crawford et al. 2009):

1) Plots subset into physiognomic classes: tree-dominated (> 25% tree cover), shrub-dominated, dwarf-shrub-dominated, herbaceous-dominated, and sparsely vegetated (< 25% total vascular plant cover). Note that these initial classes do not align with current USNVC standards that place the cutoff for sparse/rock vegetation at 10% vascular cover (Faber-Langendoen et al. 2016). This disparity was taken into account during subsequent WNHP analyses.
2) Physiognomic classes were subdivided by PCA (Pearson 1901; Hotelling 1933; Jolliffe 2002) or other clustering technique.
3) Evaluated subdivisions with TWINSPAN (Hill 1979) and/or stand table manipulation and compared them to preexisting types in the USNVC or existing literature.
4) Assigned plots individually to existing associations or preliminary/provisional types.
5) Incorporated feedback from NPS field crews and staff and prioritized additional sampling.

For more detail on field and data analysis methods used in the initial 2009 classification, please consult Crawford et al. (2009).

Mapping Phase

NPS and INR staff collected map model training data at MORA, OLYM, and NOCA from 2008-2014. The methodology evolved somewhat as the project advanced, with new challenges and insights arising during the modeling process. However, for this classification update, we analyzed only those plots with reliable GPS points at plot center and near-complete to complete species lists with cover values.

Field sampling consisted of four types of plots, with key differences from the earlier classification phase:

1) Navigational Plots— Field crews traveled to predetermined GPS points of varying “cluster types”. At each park, field crews targeted fifty clusters of unique geographic, topographic, and spectral conditions, aiming to capture the full range of ecological and spectral variation. Points were selected from relatively large patches of the same cluster, with the goal of representing patches of homogeneous vegetation and/or structure.
2) Opportunistic Plots—These were selected and sampled by field crews. Selection focused large patches vegetation that appeared homogeneous on the ground and in aerial imagery. Crews were instructed to avoid ecotonal and highly disturbed areas (unless the disturbed area supported a distinct plant community, such as an avalanche chute shrubland). Opportunistic plots were primarily used to increase the sample size of uncommon vegetation types that were not well represented in navigational or verification plots.
3) Verification Plots—These were revisits to plots used in the initial classification. Verification plots confirmed that the same vegetation was still present at that location and allowed collection of additional data to compliment map model training. Field crews assigned an association using the most up-to-date keys and mapped the extent of the vegetation patch, up to and exceeding a 40m radius (since classification plots had smaller, fixed radii).
4) Distance Plots—Some vegetation (e.g. *Nuphar polysepala* Aquatic Vegetation) or abiotic patches (lakes, talus, etc.) could be identified visually at a distance. These plots did not include full species lists and were not included in this analysis.

Aside from distance plots, all data were collected in the same manner: Crews recorded a GPS point, assigned a plant association using keys developed during the classification effort, and assigned a confidence level to the association call. Alternate calls were permitted and encouraged. The homogeneous vegetation patch was measured in each cardinal direction, with the plot ending at a 40m radius (0.5 ha), or whenever the association call would change. The minimum plot area for shrub and herbaceous types was 100 m^2 (~5.6 m radius) though this requirement was relaxed slightly for certain rare types. Sub-cardinal directions were also measured when incursions of other vegetation types were noted in those quadrants. If the plot could not be keyed to an existing plant association, it was recorded as “undescribed” and a provisional name was assigned. Small inclusions (no greater than 20% of total area) of different plant communities were permitted, but species and environmental data from inclusions were not included in the overall plot.

Whenever possible, plots were located in stands that exceeded the standard minimum mapping unit (MMU) of 0.5 ha (1.24 ac). Of course, some associations were never found to occur in such large patches, but most met the guidelines established in the NPS Field Methods for Vegetation Mapping (The Nature Conservancy & Environmental Systems Institute Inc. 1994).

Environmental data collected at each plot included: microposition, slope, aspect, standard fuel model (Scott & Burgan, 2005), and whether the site was riparian, in an avalanche chute, or had experienced some other significant disturbance such as fire or beetle-infestation.

Vegetation cover data were collected for overstory trees (> 5m), understory trees (< 5m), shrubs, and herbaceous plant species, estimated to the nearest percent. Crews identified all tree and shrub species and estimated average diameter at breast-height (DBH) for all overstory trees. Nearly all herbaceous species were identified, but plots were not always exhaustive—some plants present in trace amounts were only identified to the genus level, or frequently not recorded. Nonvascular cover was recorded, but individual species were generally only identified when those species were diagnostic dominants of the plant association (e.g. *Racomitrium canescens* - (*Penstemon davidsonii*) Nonvascular Rock Vegetation). This limits our ability to differentiate vascular-species-poor associations that may have nonvascular differential species (e.g., perhaps some forest associations in G751 North Pacific Western Hemlock - Sitka Spruce - Western Red-cedar Seasonal Rainforest). One other possible data gap of note is that *Pseudotsuga menziesii* individuals were not identified to the variety level. The study area straddles a region in which both var. *menziesii* and var. *glauca* may occur and the presence of one or the other may be used as an indicator of Vancouverian or Rocky Mountain floristic affinity of the plant community as a whole.

In the end, more than 6000 training data plots were collected. Of those, approximately 4400 had relatively complete species lists and passed other Q/A protocols necessary for inclusion in this analysis (Figure 1).

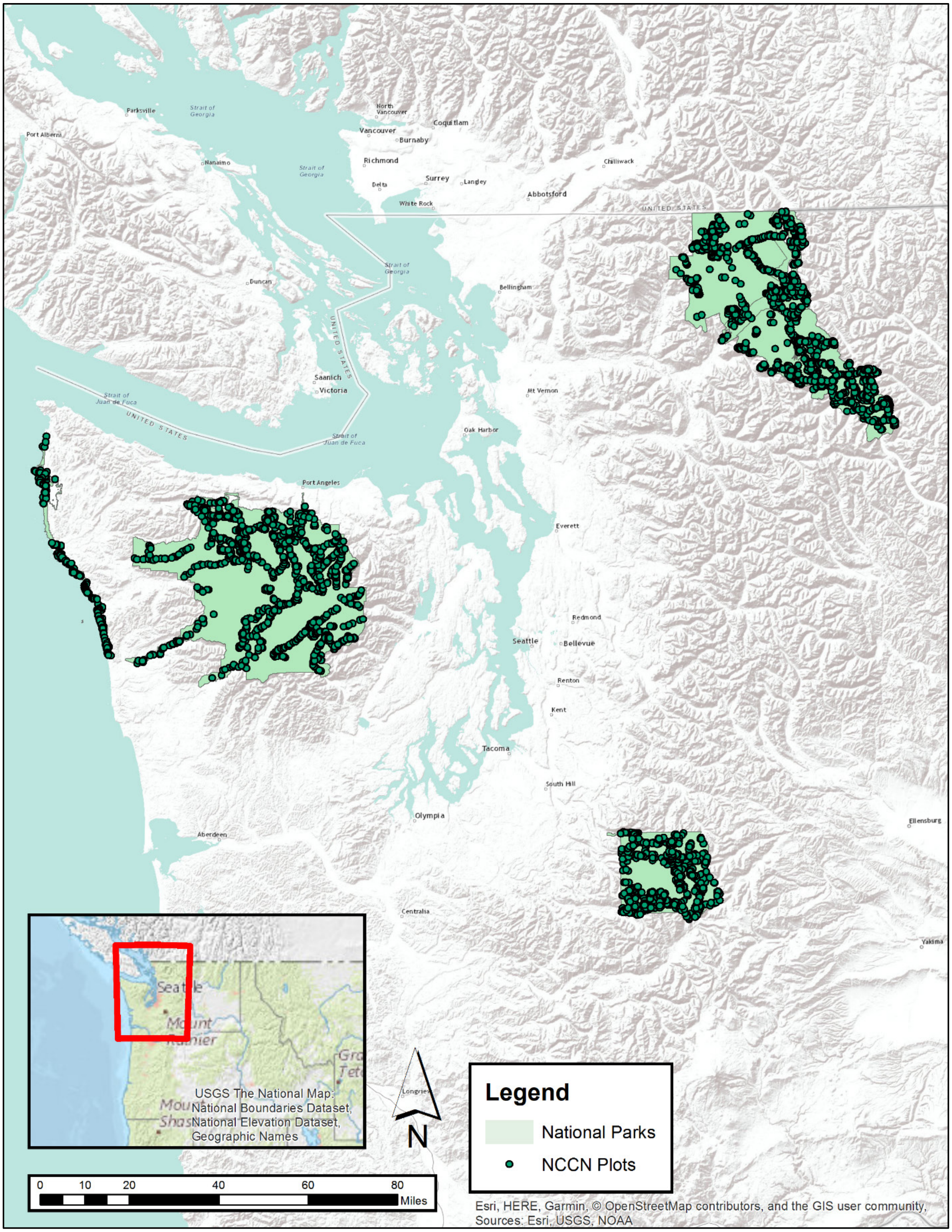

Figure 1. Map training data plots used in plant association analysis (n = 4403).

INR Analysis

While the vegetation maps were not made at the association scale, associations were rolled up into map classes that could then be mapped across the parks at the MMU (0.5 ha). When INR staff began applying these troves of new plot data to map model development, it became apparent that certain changes to the underlying classification (Crawford et al. 2009) might not only improve the quality of the map, but also improve the ecological and floristic clarity of some of the component associations.

First, INR used floristic cluster analyses of the mapping data to search for alternate groupings of plots—groupings that were more readily mappable than the original association calls made in the field (Institute for Natural Resources, 2017). Cluster analyses used k-means classification in the ‘vegclust’ and ‘vegan’ packages in R, with log (+1) transformed species cover data and Euclidean distance measures (Institute for Natural Resources, 2017). INR then reviewed the resulting clusters to see if the component plots shared ecological characteristics, particularly those characteristics explicitly used to help differentiate associations in the Crawford et al. (2009) classification (fire history, landscape position, aspect, biogeography, etc.) (Institute for Natural Resources 2017). This helped to identify groups of plots that not only mapped well together, but were also ecologically and floristically coherent. For the most part, these groupings divided “catch-all” associations such as *Ceanothus velutinus* Shrubland and/or formerly under-sampled types such as non-forested wetlands. INR dubbed these new groupings “mapping associations”.

Second, INR used an iterative cluster analysis approach that they termed “Species Cover - Association Match” (SCAM). In this approach, they used multivariate analysis to calculate the centroid of each Crawford et al. (2009) association based on the floristic composition of its plots, then calculated the distance from each plot to each centroid and summarized these in ranked lists (Institute for Natural Resources 2017). INR individually reviewed plots that were closer to the centroid of a different association than the one assigned by the field crews. Such plots were then reassigned to their closer SCAM-match only if they also matched the setting and structure of that association. This whole process was then repeated iteratively, using centroids that included association call changes arising from the previous round of SCAM. These analyses again used the ‘vegclust’ R package, with a log (+1) transformed matrix of species data. INR chose to weight trees (3x) and shrubs (2x) in an effort to match the structural hierarchy of the USNVC (Institute for Natural Resources, 2017). SCAM proved to be a valuable data validation mechanism, as it helped identify outlier plots resulting from recent disturbance, human data collection error, and varying interpretations of the association key and descriptions, etc.

After reassigning plots using the SCAM cluster analysis, INR condensed and summarized the results by producing “similarity ratios” for each “mapping association”. These ratios were produced by taking the average distance (in floristic space) for all plots within a given mapping association to the centroid of an alternate (“incorrect”) association, and then dividing that by the average distance to the assigned (“correct”) association. Note that these ratios are purely descriptive in nature and did not factor into the creation of the mapping associations themselves, but they proved useful in illustrating the relationships between mapping associations.

INR also produced indicator species values (both single-class and pairwise) for each association (Dufrêne & Legendre 1997). Single-class results measure the indicator value of a species when comparing a given association to all other plots combined, while pairwise results measure the indicator value of a given species in a head-to-head comparison of two associations. The statistics calculated were: positive predictive value (having found this species, likelihood that one is in the target association), sensitivity/constancy (likelihood that one would find this species in the target association), and indicator value (√(Predictive Value*Sensitivity)). All values were calculated using the function 'multipatt' in the R package 'indicspecies' (Dufrêne & Legendre 1997) and only results with p-values < 0.05 were retained.

WNHP - USNVC Synthesis Phase

Association Review

WNHP was consulted to determine which of the new and modified types, dubbed "mapping associations" in INR documents, fit the criteria for USNVC plant associations within a region-wide context. These types were then moved through the peer-review process. Some types that were lumped together for mapping purposes by INR remain ecologically distinct plant associations from a classification perspective. These types may occur in patches that are too small to be mapped using a modeling approach, or mapping via a modeling process might require data layers that are not currently available (e.g. water table depth). Other types created in the INR reclustering process represent distinct new associations arising from the vastly expanded data set. In addition, INR proposed various association name changes and description updates that we also reviewed.

INR provided a crosswalk describing modifications made to the original Crawford et al. (2009) plant association concepts over the course of the mapping project. WNHP reviewed this in concert with the draft INR descriptions and original Crawford et al. (2009) descriptions. We also consulted floristic similarity indices and ecological setting summaries provided by INR. During this initial review, we updated the current EL code, name, and hierarchy placement for each type that already existed in the USNVC, noted if it was an upland or wetland type, and made minor name changes to abide by USNVC conventions.

WNHP analysis began by comparing updated INR constancy tables with those produced for Crawford et al. (2009). We also reviewed synonymous types for regional context and descriptions from USNVC.org and other NatureServe resources for global context on each of these types. We used Nonmetric Multidimensional Scaling analyses (NMS) (Mather 1976; Kruskal & Wish 1978; McCune et al. 2002; McCune & Mefford 2011) to compare each association with floristically similar types. We ran NMS using the Sørensen (Bray-Curtis) distance measure, random starting configurations based on the time of day, 250 runs with real data, and a stability criterion of 0.000001. We chose the number of dimensions beyond which additional axes provided only minimal reductions in stress and checked this using Monte Carlo tests (Metropolis & Ulam 1949). Multi-response Permutation Procedures (MRPP) analyses were then used to confirm the degree of difference (Mielke Jr et al. 1976; McCune et al. 2002; McCune & Mefford 2011). We used Sørensen (Bray-Curtis) distance measures to match the ordination being assessed (McCune et al. 2002). Species cover data were log (+1) transformed, but we also confirmed that the use of raw data or Beals smoothing (Beals

1984) did not meaningfully impact the interpretations in a selection of test cases. Plot-level data were consulted when individual outliers arose. Lastly, we used Indicator Species Analysis (ISA) (Dufrêne & Legendre 1997) to identify diagnostic/differential species for each association relative to other associations within the same alliance (whether tentative, or confirmed). ISA was performed using quantitative responses (Dufrêne & Legendre ISA eqn. 1), a randomization test, 4999 runs, and a 'time of day' starting seed. All WNHP statistical analyses and ordinations were done using PC-ORD v.7.03 (McCune & Mefford 2011). The general idea of this process was to confirm that the distinct types identified through INR's clustering process and SCAM tool were corroborated via another method that was already widely used and accepted.

In addition to standard environmental measures like aspect, slope, and elevation, INR calculated a number of environmental variables in the course of their modeling process. While these were not used in the INR analysis of the classification, WNHP fit and tested vectors for environmental variables through the NMS plots. The environmental data proved useful in helping to interpret some of the NMS axes and describe new associations and alliances. Environmental variables used in analysis are described in Table 2.

Table 2. Environmental variables used in analysis. *Wetland plots only. †WNHP plots only.

Abbreviation	Variable	Notes
vd_river	Vertical distance (m) above a river	Based on hydrological flow accumulation modeled using SAGA (http://www.saga-gis.org/en/index.html).
vd_perm	Vertical distance (m) above nearest permanent stream	Based on hydrological flow accumulation modeled using SAGA (http://www.saga-gis.org/en/index.html).
tmax_jan	Maximum temperature (°C) in January	Based on PRISM 30 year normal. (PRISM Climate Group, 2019)
tmax_jul	Maximum temperature (°C) in July	Based on PRISM 30 year normal. (PRISM Climate Group, 2019)
ppt_jan	January precipitation average (mm)	Based on PRISM 30 year normal. (PRISM Climate Group, 2019)
ppt_jul	July precipitation average (mm)	Based on PRISM 30 year normal. (PRISM Climate Group, 2019)
tpp_300m/ 1500m	Topographic position percentile	An elevation percentile ranking relative to the area around a point (300m / 1500m radius). Range = 0 to 100.
curv_45m/ 225m	Convexity/concavity of the site	A measure of curvature within 45m or 225m radius. Range = -1 to 1. Positive values are convex.
dir_rad	Daily direct radiation from the sun	Scaled 0 (min) to 1 (max).
wetness	Topographic wetness metric	Scaled 0 to 1, with 1 being the wettest (along rivers)
utme	UTM easting coordinate (m)	Only useful for comparing associations w/i a single park
utmn	UTM northing coordinate (m)	Only useful for comparing associations w/i a single park
elev	Elevation (m)	Derived from USGS digital elevation model and park-specific LiDAR

Table 2 (continued). Environmental variables used in analysis. *Wetland plots only. †WNHP plots only.

Abbreviation	Variable	Notes
slope	Slope (°)	Derived from USGS digital elevation model and park-specific LiDAR
eastness	East-west component of aspect	Scaled -1 to 1 (sin(aspect in radians), 1 = due east))
southness	North-south component of aspect	Scaled -1 to 1 (-cos(aspect in radians), 1 = due south))
*Wetland_type	Broad wetland type	Ruderal, Riparian, Aquatic, Marsh/wet meadow, Swamp, Shrub Carr, Intermediate fen, Poor fen, Extremely Rich Fen, Bog, Bog Woodland, Seep/Spring
†HGM	Hydrogeomorphic Wetland Classification	Riverine, Depressional, Slope, Floating Mat, Organic-Flat, Freshwater-Tidal, Depressional-Interdunal
Ecoregion	Ecoregion	Columbia Plateau, North Cascades, Northwest Coast, West Cascades, East Cascades, Canadian Rocky Mountains, Okanogan, Blue Mountains, Puget Trough
*Lithology	General physical characteristics of the bedrock	Based on WA DNR Geology data layers — https://www.dnr.wa.gov/geologyportal
†pH	pH	Acidity
†Corrected_EC	Electro-conductivity	Corrected for pH

Because data collection methodology evolved over the 10-year span of fieldwork, not all plots had thorough species lists. Only plots with relatively complete species lists were used in our analyses. For these plots, one can assume that indicator species not represented in the data are truly absent. To avoid excluding taxa commonly recorded at the genus level, INR chose to lump certain species together during their classification and mapping procedures (e.g. sedges occupying similar habitats). This was also done for certain species that can be difficult to differentiate and have similar ecological requirements, such as *Arctostaphylos uva-ursi* and *A. nevadensis*. Species were generally "unlumped" for our review. Plants identified only to the family level or higher were removed from the data set if a finer *post hoc* identification was not possible.

For certain vegetation types, we had additional plot data on hand that we included in the analysis of NCCN mapping and classification plots. WNHP has recently conducted extensive EPA-funded wetland classification work (e.g. Rocchio & Ramm-Granberg 2017) and those plots were included in wetland analyses. Additional data sets and their applications are described in Table 3. All data sets had existing plant association calls (updated to current USNVC hierarchy 36, USNVC v.2.03), full species locations, and (in most cases) GPS locations for modeling climate and topographic data (Figure 2). Wetland associations were rekeyed using WNHP's statewide wetland association key (Rocchio et al. 2020). Some plots without GPS locations were used for certain uncommon types, such as low-elevation balds, in which case it was not possible to evaluate abiotic correlates of floristic separation.

Table 3. Additional vegetation plot data sets used in analysis.

Reference	Vegetation types / Location	Plots (Full Data Set)
Kovalchik & Clausnitzer (2004)	Eastern Washington and Gifford Pinchot National Forest US Forest Service Wetland Data	2111
WNHP plot data (Rocchio / Crawford)	Statewide wetlands	620
Houston et al. (1994)	Herbaceous, dwarf-shrub, and sparse subalpine/alpine vegetation at OLYM	156
Chappell (2006a)	Lowland western Washington vegetated balds	258
Chappell (2006b)	Lowland western Washington forests	701
Chappell (1999)	Olympic Peninsula riparian	129
Kunze (1989, 1990, 1991, 1994)	Coastal wetlands, Puget Lowland bogs, Puget Lowland wetlands, West Cascades wetlands	488
Hawk (1973)	Oregon riparian forests	54

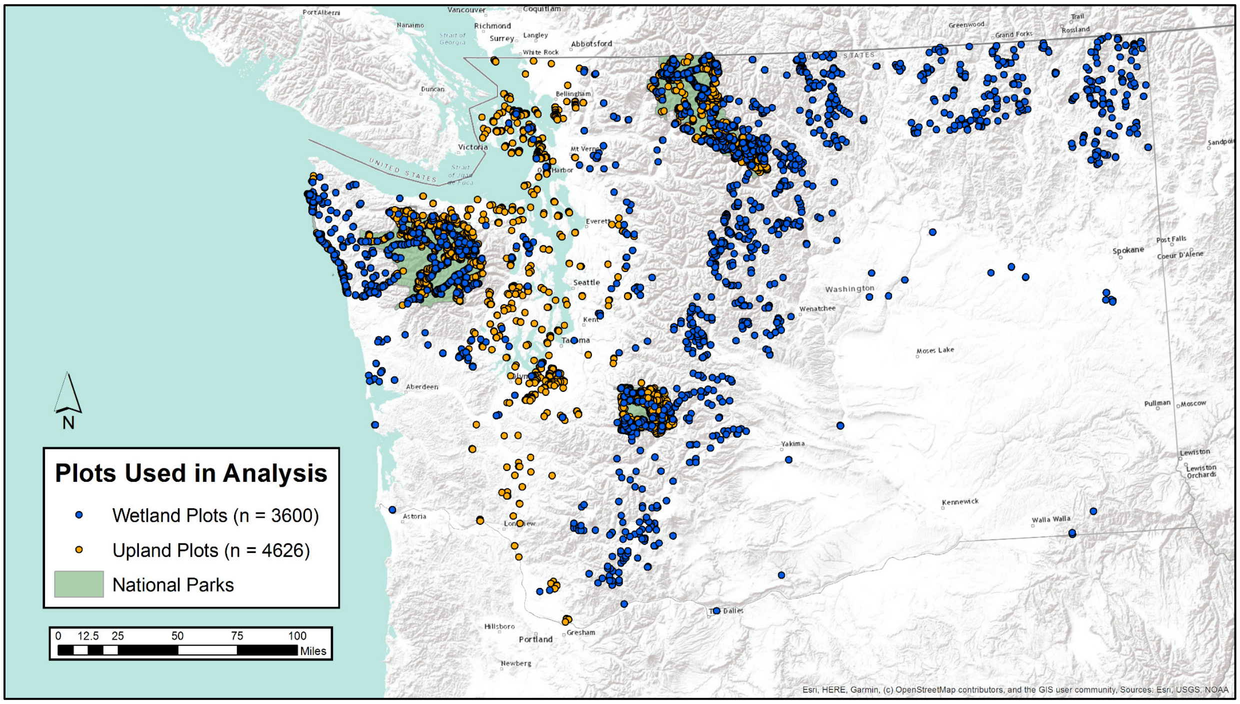

Figure 2. Map of full data set (upland and wetland plots) used in WNHP analysis.

Even with these added data sets, it is important to note that we were unable conduct a full statistical comparison across the full geographic range of many of the associations in question, particularly those in the Rocky Mountain Forest & Woodland Division (1.B.2.Nb). Our study area covers only the far western margin of where this division occurs. In many cases, we relied on comparison against summary/synoptic tables (Table 4) or association descriptions to determine if apparently new types from the parks simply represented variation within existing associations at the edge of their ranges.

Table 4. Classifications lacking available plot data, but used for comparison with NCCN types using summary tables and/or descriptions.

Reference	Title
Lillybridge et al. (1995)	Forested plant associations of the Wenatchee National Forest
Diaz & Mellen (1996)	Riparian ecological types of the Gifford Pinchot and Mt. Hood National Forests, Columbia River Gorge National Scenic Area
Wooten & Morrison (Wooten & Morrison, 1995)	Classification of vascular plant communities of the North Cascades using discrete space boundary analysis
Williams & Lillybridge (1983)	Forested plant associations of the Okanogan National Forest
John et al. (1988)	Forest plant associations of the Yakima Indian Reservation
Franklin (1966)	Vegetation and soils in the subalpine forests of the southern Washington Cascade Range
Douglas & Bliss (1977)	Alpine and high subalpine plant communities of the North Cascades Range, Washington and British Columbia
del Moral (1979)	High elevation vegetation of the Enchantment Lakes basin, Washington
Henderson (1973)	Composition, Distribution and Succession of Subalpine Meadows in Mount Rainier National Park
Kuramoto & Bliss (1970)	Ecology of subalpine meadows in the Olympic Mountains, Washington

Wetland Group and Alliance Review

For wetland plant communities, WNHP focused analysis on group and alliance-level changes to the USNVC, rather than proposing a suite of new plant associations. This approach was taken for several reasons:

1) In initial analysis, we recognized that several INR wetland mapping associations were equivalent in scale to USNVC alliances. In other words, rather than representing new associations, they lumped together multiple associations that WNHP still recognizes as separate units.
2) All remaining proposed mapping associations were equivalent to state types already recognized in the Washington state wetland classification (Rocchio et al. 2020). These state types have not been advanced through the peer-review process, but they have provisional USNVC hierarchy placements.
3) WNHP has long recognized that many USNVC wetland alliances are overly floristic in nature—this project provided an opportunity to identify improved alliance concepts that better capture ecological differences observed in the field.
4) Alliances are the mapping standard for NPS projects.

WNHP first reviewed our statewide wetland classification and, for each association, assigned a probability of that type occurring at MORA, NOCA, and/or OLYM. The following probability categories were used: Confirmed, High, Moderate, Low, or Not Present. USNVC groups with "confirmed" or "high" probability associations were targeted for alliance analysis. From that subset, WNHP prioritized review of groups containing INR wetland mapping associations (Table 5).

Table 5. Groups prioritized for alliance review. *G284 was also analyzed.

Division	Groups (# of INR mapping associations to review)
1.B.3.Nc Rocky Mountain & Great Basin Montane Flooded & Swamp Forest Division	G505 (1)
1.B.3.Ng Vancouverian Flooded & Swamp Forest Division	G507 (1) G851 (6) G853 (4)
2.C.2.Na North American Bog & Fen Division*	G285 (3) G610 (2)
2.C.4.Nb Western North American Freshwater Shrubland, Wet Meadow & Marsh Division	G322 (8) G517 (3) G520 (3) G521 (1) G524 (1) G527 (3)

Wetland group and alliance analysis followed the same basic methodology as the review of upland associations. NMS was used to compare floristic similarity and ecological patterns, MRPP was used to confirm the degree of difference between groups/alliances, and ISA (along with basic synoptic table review) were used to find differential species.

Peer Review

The USNVC peer review process is managed by the Ecological Society of America, NatureServe, and other NVC partners. The NVC Review Board identified regional and associate editors with whom WNHP worked to complete peer review of all proposed classification changes. Editors were typically regional experts from academia, government agencies, or other individuals with expert knowledge of the types in question. NatureServe staff assisted WNHP with the logistics of the peer review.

Proposed changes were bundled based on USNVC divisions and presented to peer-reviewers at in-person meetings and webinars. Peer-review feedback was then incorporated into final proposals that were submitted to the regional editors. Classification updates will now be published in the Proceedings of the National Vegetation Classification and reflected in the USNVC hierarchy (http://usnvc.org) and WNHP's BIOTICS database. For more information on the peer review process, visit http://usnvc.org/revisions/.

Updates to Key and Descriptions

Due to changes in nomenclature and the USNVC hierarchy—including changes made by WNHP through the peer review process—the keys and descriptions for all associations in Crawford et al. (2009) were updated. Additional floristic and environmental information was incorporated when new patterns came to light in the compiled plot data. Many new classification comments were added to descriptions to help differentiate associations and alliances from similar communities in the USNVC. New associations were also incorporated into the key and descriptions. The key was further modified based on feedback from INR and field crews.

Results

A key to the plant associations of Mount Rainier and Olympic National Parks and the North Cascades National Park Complex are presented in Ramm-Granberg et al. (2021a), along with revised association descriptions for all upland plant associations. As in Crawford et al. (2009), Ramm-Granberg et al. (2021a) includes forested wetland associations and a selection of common wet shrubland, peatland, marsh, and wet meadow associations. The remaining wetland types are also described at the alliance level in Ramm-Granberg et al. (2021a).

Association and alliance descriptions are based on range-wide plot data and references, with a special focus on their characteristics in NCCN park units. Of the 375 association concepts in Crawford et al. (2009), 171 were accepted in the USNVC as of 2019 (hierarchy 36, USNVC v2.03), while 204 remained as preliminary/provisional associations. This 2020 update to the key contains a total of 321 plant associations, with 235 of those fully described (Table 6). The remainder are described at the alliance level in Ramm-Granberg et al. (2021a) (48 wetland alliances). While most associations are represented by plot data from the parks, 71 associations (22%) are based on non-NPS data alone (yet remain likely to occur within park boundaries). The vast majority of those unrepresented types (63) are wetland associations. There were 63 provisional/preliminary associations recognized in Crawford et al. (2009) that were not subsequently supported by additional plot data—these have been excluded from this classification update. Many of those unsupported provisional types are mentioned as classification comments in the descriptions for similar, retained associations. There were 25 USNVC-recognized associations included in Crawford et al. (2009) that we no longer consider as occurring in the parks. On the other hand, there are 62 associations in this classification that were not included in Crawford et al. (2009) (11 upland and 51 wetland associations).

Table 6. Number of plant associations at MORA, NOCA, and OLYM by USNVC division.

Division	**# of Associations (USNVC and State types)**
1.B.2.Nb Rocky Mountain Forest & Woodland	28
1.B.2.Nd Vancouverian Forest & Woodland	85
1.B.3.Nc Rocky Mountain-Great Basin Montane Flooded & Swamp Forest	11
1.B.3.Ng Vancouverian Flooded & Swamp Forest	36
2.B.2.Na Western North American Grassland & Shrubland	28
2.B.2.Nd Western North American Interior Chaparral	3
2.C.2.Na North American Bog & Fen	32
2.C.4.Nb Western North American Freshwater Shrubland, Wet Meadow & Marsh	56
4.B.1.Nb Western North American Alpine Tundra	27
5.B.2.Na North American Freshwater Aquatic Vegetation	15
Total	**321**

A total of 54 upland associations were moved through the peer review process and are now part of the USNVC (Table 7). Of those, 45 were originally proposed in Crawford et al. (2009), with 9 additional new associations proposed by INR. WNHP also revised the concepts of 34 associations, wrote descriptions for 2 existing associations, eliminated 2 associations, and created 4 new upland alliances. WNHP created 27 new USNVC wetland alliances and revised or clarified the concepts for an additional 21 (Table 8).

Table 7. Breakdown of new, revised, and unchanged USNVC upland associations and alliances by division.

Division	New (Crawford 2009)	New (INR)	Revised	Description Written	Eliminated	No Change	New Alliances
1.B.2.Nb Rocky Mountain Forest & Woodland	10	2	7	–	–	10	–
1.B.2.Nd Vancouverian Forest & Woodland	10	1	16	2	–	51	–
2.B.2.Na Western North American Grassland & Shrubland	15	2	2	–	–	7	4
2.B.2.Nd Western North American Interior Chaparral	0	2	1	–	–	–	–
4.B.1.Nb Western North American Alpine Tundra	10	2	8	–	2	5	–
Total	**45**	**9**	**34**	**2**	**2**	**73**	**4**

Table 8. Breakdown of new and revised USNVC wetland alliances by division.

Row Labels	New	Revised	Total
1.B.3.Nc Rocky Mountain & Great Basin Montane Flooded & Swamp Forest	3	8	11
1.B.3.Ng Vancouverian Flooded & Swamp Forest Division	2	7	9
2.C.2.Na North American Bog & Fen Division	7	-	7
2.C.4.Nb Western North American Freshwater Shrubland, Wet Meadow & Marsh	15	6	21
Total	27	21	48

A field key for identifying plant associations precedes the association descriptions in Section A of Ramm-Granberg et al. (2021a). This key may also be used to identify wetland alliances (if the association to which you key is not described in Section A, the key will direct you to the appropriate alliance description in Section B. The key and descriptions include some associations/alliances that were not sampled during map training data collection but are highly likely to occur in the parks. These generally represent types that occur in patches too small or linear—or are too difficult to access—to be sampled with the map training methodology. Supporting synoptic tables for associations and alliances are presented in Ramm-Granberg et al. (2021b). Environmental summary tables for associations and alliances may be found in Ramm-Granberg et al. (2021c). Lastly, Ramm-Granberg et al. (2021d) presents a crosswalk from associations in Crawford et al. (2009).

Conclusions

While expansive in its scope, Crawford et al. (2009) also identified several areas in which the initial classification could be improved:

North Cascades Sampling

This was previously the least sampled park unit. Because it is the only NCCN park unit to span both sides of the Cascade Crest, NOCA has far more Rocky Mountain biogeographic influence than the other parks. NOCA was known to contain vegetation types for which the classification likely needed further modification (such as dry shrublands of the East Cascades). The addition of 1939 plots has largely addressed this data gap—30 of the new associations and 13 of the revised/new alliances advanced through peer review are found primarily or only at NOCA (among the three park units).

Wetlands

The Crawford et al. (2009) association classification was created to support vegetation mapping, so more effort was applied to sampling matrix vegetation. Minimal sampling was conducted for relatively small-scale associations, such as those occurring in wetlands. More broadly, wetland vegetation is generally under-sampled because of differences in sampling protocols and the need for additional training and expertise from field staff. While Crawford et al. (2009) noted that forested and shrub wetlands were fairly well described, the majority of herbaceous wetland communities likely to occur in the parks were absent from their data set. Filling these data gaps is critical to providing a comprehensive list of associations likely present in INR map classes and thus found within the three Parks. Wetlands represent 18% of all map classes and approximately 8-14% of the mapped area within the three parks. In addition, although wetlands are generally a small proportion of the landscape, they have disproportionate importance for wildlife and other ecosystem processes. For example, wetlands are estimated to represent approximately 2% of Washington's landscape but are utilized by over 66% of the state's terrestrial vertebrates (Sheldon et al., 2005). Because of their steep, narrow ecological gradients, wetlands also support a disproportionately high percentage (53%) of all the USNVC associations documented in Washington State.

WNHP has conducted extensive wetland sampling and statewide classification updates (funded by the EPA) in the years since Crawford et al. (2009) was published. We were able to leverage that body of work—along with hundreds of map training plots—to greatly improve the wetland keys and classification for the NCCN parks. We now have a more comprehensive understanding of the diversity of vegetation patterns within the NCCN wetland map classes (and western Washington in general). That understanding will also support more effective management of these important habitats.

Sparsely Vegetated Alpine and Lithomorphic Communities

These were only minimally sampled during classification data collection and were represented primarily by legacy data sets from OLYM (e.g., Houston et al. 1994). These communities are difficult from both a sampling and classification perspective. They typically have low species diversity, prominent nonvascular species that are difficult to identify in the field, small patch size, and occur in heterogeneous landscapes. They are simply difficult to access, as well.

At the conclusion of this project, 693 additional alpine and bedrock plots had been collected and 17 new associations were moved into the USNVC, filling a significant data gap. However, many of the same challenges remain. Besides the access issue, nonvascular species were only infrequently identified in plot data and most occurrences of these communities are simply too small to have been documented with map training methodology. Further improvement in alpine and lithomorphic classification requires more targeted sampling.

In addition to addressing these data gaps, this report represents the current, “best practice” taxonomic treatment of the plant communities of MORA, OLYM, and NOCA. The community descriptions, synoptic tables, environmental summaries, and crosswalk tables presented here ensure that park management has the best NVC-based knowledge available with which to manage these iconic parks.

Sunset in the North Cascades (Photograph by Tynan Ramm-Granberg).

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