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Forest Vegetation Monitoring Protocol (Version 2.1)

Great Lakes Inventory and Monitoring Network



Isle Royale National Park, viewed northward from Ojibway Tower.
NPS / JESSICA KIRSCHBAUM

Forest vegetation monitoring protocol (version 2.1): Great Lakes Inventory and Monitoring Network

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Contents

Page

Figures v

Tables v

Abstract vi

Revision History Log vii

Acknowledgements ix

Background and Objectives 1

- Rationale for Monitoring Vegetation Communities 1
- Network Parks and Ecosystems 1
- Current Threats to Vegetation in NPS Units 3
- Overview of Vegetation Monitoring at the Great Lakes Network Parks 5
- Measurable Objectives 6

Overall Sampling Design 8

- Rationale for Selecting This Sampling Design Over Others 8
- Sampling Frame, Plot Design, and Metrics 8
- Sampling Frequency, Replication, and Timing 11
- Recommended Number of Sampling Sites and Frequency 12
- Sample Method Selection and Level of Change That Can Be Detected 12

Field Methods 14

- Field Season Preparations and Equipment Setup 14
- Sequence of Events During Field Season 14
- Details of Taking Measurements 15
- Post-Collection Processing of Samples 15
- End-of-Season Procedures 15

Data Handling, Analysis, and Reporting 16

- Overview of Database Design 16
- Data Collection, Entry, and Editing 16
- Metadata Procedures 16
- Recommendations for Data Summaries and Analyses and Reporting Schedule 16

Contents (continued)

Page

Recommended Methods for Analysis 17
Data Archival Procedures 17
Personnel Requirements and Training 18
Roles and Responsibilities 18
Crew Qualifications 19
Training 20
Operational Requirements 21
Annual Workload and Field Schedule 21
Facility and Equipment Needs 21
Budget Considerations 21
Procedures for Revising the Protocol 21
Literature Cited 23

Figures

Page

Figure 1. Nine national park units of the Great Lakes Inventory and Monitoring Network..... 1

Figure 2. Left: scale diagram of the hybrid plot, showing three parallel belt transects and areas for data collection of tree, groundlayer, and coarse woody material metrics. Right: hybrid plot showing where direct browse and shrub data are collected. 10

Tables

Page

Table 1. Revision history log. vii

Table 2. Sampling frame for each of the nine GLKN parks. Within these defined frames, sampling will also be restricted to forested areas. Inholdings are excluded. 8

Table 3. Schedule for the first two monitoring rotations at each park and the planned year for the third monitoring rotation. No field work was done in 2020 due to the COVID-19 pandemic. 12

Table 4. Sampling effort in each park in relation to sampling area available. 13

Abstract

Forest vegetation provides an integrated measure of terrestrial ecosystem health by expressing information about the collective suite of drivers and stressors which act upon it. These include climate, disturbance, browse, and invasive species. We developed a comprehensive forest monitoring protocol to detect change in the nine Great Lakes Network parks. Monitoring is conducted on a nine-year rotation, with each of the parks sampled over the course of one summer, once every nine years. Site locations were selected to ensure that they are random, but also spatially balanced throughout the parks. At each sampling site, we collect extensive data on trees (including saplings and seedlings), shrubs, herbs, coarse woody material, and browse. We also carry out assessments of tree health. Data are housed in a Microsoft Access database, and appropriate metadata are generated annually. Quality control measures include both on site assessments of accuracy, as well as extensive data checking via automated parsing routines. Finally, reports from monitoring are produced on a regular basis and include internal National Park Service technical reports and externally reviewed manuscripts for publication in peer-reviewed journals. All data are publicly available.

Revision History Log

Revision history logs recording the major changes to each version of a protocol are a required element for all Inventory and Monitoring Division protocols (Table 1).

Table 1. Revision history log.

Date	Previous version	New version	Items changed
2023	2.0	2.1	• We had a number of inconsistencies with respect to the Vital Signs covered in the protocol, monitoring questions, and organization. These inconsistencies related to succession, deer browse, pests and pathogens, and earthworms. These were brought into alignment in this version. • We changed the wording on the rotation. Instead of nine-year rotation, it is changed to, “generally one park visited each year.” Problems arise that we cannot foresee, and the rotation can get thrown off, so the revised wording allows more flexibility. • At the time of publication, seasonal staff are no longer hired via the federal system, but through a cooperative agreement. The wording was changed to make it more general, and applicable to either situation. • Following the 2022 field season, and the completion of the second round of sampling, we no longer plan to produce annual data summaries or technical reports. All references to this were changed. Additionally, we have not and do not plan to produce analysis and synthesis reports, as envisioned in the earlier protocol versions. References to these were removed. • We removed all references to supplemental document #2. This document was planned to be a report detailing the database structure and serving as a user guide, but was not completed as envisioned. • Now that data collection is via tablets, a number of things needed to be updated. This includes everything related to data sheets and field data collection, data entry and checking, and photos. We also added wording to address data transfer and tablet backup. • We have made numerous small edits throughout this document to improve wording flow. This includes changing “plot” to “site,” as appropriate. • Many references were updated. Because updates to this protocol for version 2.0 in 2014 were limited, most references were from earlier than 2007. We updated them to 2012 or later if possible; when it was not, we attempted to find references from 2000 or later. • Metadata generation requirements were changed to reflect that we are now using the R-based package EMLassemblyline. • All references to “Indiana Dunes National Lakeshore” have been updated to reflect its new status as a national park.

Table 1 (continued). Revision history log.

Date	Previous version	New version	Items changed
2014	1.0	2.0	• All references to GLKN's use of plots in the style of the Forest Service Forest Inventory and Analysis Program (FIA) have been removed. • We now sample on a nine-year rotation, rather than six-year rotation. • Methods to assess deer browse were updated. • Sampling methods for shrubs have been modified. • A number of minor revisions have also been made and are detailed in the bullets below. • The causal agent of beach bark disease was clarified. • The intended sampling frame at ISRO was changed from only the main island to the entire park, and at PIRO from all areas of federally owned land to the entire core area and the inland buffer zone, whether owned by the State of Michigan or private entities. • Details of permanently marking plots were added, including the use of aluminum tags on witness trees and the use of yellow rebar endcaps. • The target minimum number of plots to sample at each park was revised for many parks to reflect the nine-year, rather than five-year, rotation. • The Field Crew Leader position was revised to a permanent Botanist and the duties of both the Botanist and Terrestrial Ecologist were refined. • The field schedule section was revised to indicate a training period longer than was originally intended. • In the Equipment Needs section, the references to needing a great deal of park assistance for boating and shuttling have been removed. This is because the network has purchased several additional vessels that network staff can use to access plots.

Acknowledgements

Updates to this protocol since the last version have been driven by input and expertise from numerous individuals. Most notably, R. Key has assisted us with all aspects of data transfer and data management. Our reporting and data management techniques have changed immensely over the previous nine years, thanks to her help. We are also grateful to T. Gostomski for providing us reporting assistance every year. His direction and guidance, whether it is with our technical reports or with park and public outreach, helps to ensure that we remain relevant for all audiences. Finally, we are most grateful to the 41 seasonal employees who have worked for us during the first 15 years of implementation of this program. Their contributions and their insight have allowed the continual improvement of techniques, both in the field and office.

Background and Objectives

Rationale for Monitoring Vegetation Communities

Terrestrial vegetation was ranked third among all 46 Vital Signs evaluated by the National Park Service (NPS) Great Lakes Network for incorporation into a long-term monitoring strategy. Terrestrial vegetation serves as an integrated measure of terrestrial ecosystem health by expressing information about climate, soils, and disturbance (Franklin et al. 2016), as well as browse (Blossey et al. 2019), and invasive species (Pyšek et al. 2022). In order to tease apart these interwoven relationships between terrestrial vegetation and both biotic and abiotic components, we have developed a comprehensive protocol that incorporates the network's monitoring plans for terrestrial vegetation as well as those of related Vital Signs, including terrestrial pests and pathogens, problem species, and succession. Because forests predominate the landscape in the Great Lakes Network national parks (Route and Elias 2007), this protocol will focus exclusively on forested vegetation.

Network Parks and Ecosystems

The nine park units of the Great Lakes Inventory and Monitoring Network (GLKN) extend from the boreal forests of northern Minnesota to the sand dunes of southern Lake Michigan (Figure 1). Collectively, these parks support all major types of freshwater and terrestrial ecosystems of the upper Midwest.



Figure 1. Nine national park units of the Great Lakes Inventory and Monitoring Network.

Apostle Islands National Lakeshore (APIS) is located near Bayfield in extreme northwestern Wisconsin. It consists of 21 islands, ranging in size from 1 to 4,000 hectares, and a 19-kilometer linear segment along the mainland shore of Lake Superior. The lakeshore is at the northwestern limits of the hemlock-white pine and northern hardwood forest and also contains elements of the southern boreal forest. The lakeshore has a wide variety of sandscapes such as barrier spits, cuspate forelands, beaches, and dunes that provide unique habitats for plants and wildlife. In addition, 13,560 hectares of the park have been designated as wilderness.

Grand Portage National Monument (GRPO) is located 56 kilometers northeast of Grand Marais, Minnesota, in the extreme northeastern "arrowhead" region of the state near the Canadian border. The monument protects 287 hectares of land including the historic trading post of the North West Company on Lake Superior, the site of Fort Charlotte on the Pigeon River, and a 13.7-kilometer historic canoe portage trail that connects the two sites. The portage trail crosses several riparian areas and over the Grand Portage Highlands with a 240-meter rise in elevation. The area is covered by a near-boreal forest, with birch-aspen-spruce-fir communities dominating most sites. The Grand Portage trail corridor bisects the Grand Portage Band of Minnesota Chippewa Reservation. Surrounding land use greatly influences resource management at GRPO. Forestry practices on Reservation lands are carefully integrated with wildlife management objectives, and large areas are set aside to preserve the near-wilderness character of the region.

Indiana Dunes National Park (INDU) spans approximately 40 kilometers along southern Lake Michigan and includes 6,070 hectares. Biological diversity is one of the most significant features of the park and a primary reason for its establishment. This diversity is greater than most areas of similar size because Indiana Dunes lies at the convergence of several ecological zones and includes components of northern conifer forests, temperate hardwood forests, and tallgrass prairies. Diverse habitat types include beaches, bogs, prairies, black oak savannas, forests, wetlands, and marshes. The park is composed of unconsolidated soils on which landforms range from open beach and active dunes to stabilized and extensively vegetated older dunes and moraines. Some dunes, like Mount Baldy, rise to heights of over 30 meters above the shoreline.

Isle Royale National Park (ISRO) is a remote island archipelago in northwestern Lake Superior. It consists of one large island, 72 × 14 km at the largest dimensions, surrounded by about 400 small islands. The park protects 53,540 hectares of land, with 53,426 hectares (>99%) designated as wilderness. The island is densely forested, with northern boreal spruce-fir forest near the cool, moist shoreline of Lake Superior and northern hardwoods in the warmer, drier interior. Inland lakes, ponds, and streams are numerous throughout Isle Royale.

Mississippi National River and Recreation Area (MISS) extends 116 kilometers along the Mississippi River and six kilometers along the Minnesota River and encompasses about 21,800 hectares of public and private land and water. This section of river, some of which flows through metropolitan St. Paul and Minneapolis, is a major transportation corridor and yet a place for recreation and quiet in the midst of an urban environment. The numerous private, state, county, and other federal landowners make management of access, resource use, and development complex. The

rivers themselves, and the riparian zones along the shorelines and islands, are the primary biotic communities of interest.

Pictured Rocks National Lakeshore (PIRO) protects 28,893 hectares of land including 67 kilometers of Lake Superior shoreline and 4,751 hectares within the Beaver Basin Wilderness. The park is located along the south-central shore of Lake Superior within a transition zone between the boreal and eastern deciduous forest biomes. Hardwood forests are prevalent, although conifers dominate some sites, and wetlands are common throughout the park. The cold, moist climate along the lakeshore greatly influences the biotic communities. The park is divided into two distinct ownership and management zones: the federally owned shoreline zone, known as the "core," and a non-federal "inland buffer zone." Sustained-yield timber harvesting and other consumptive uses are allowed in the inland buffer zone; however, these uses were intended by Congress to be subordinate to public recreation and the protection of "the usefulness and attractiveness of the lakeshore."

The St. Croix National Scenic Riverway (SACN) protects 37,529 hectares including 405 kilometers of the St. Croix and Namekagon Rivers in eastern Minnesota and northwest Wisconsin. The park spans three major biomes: boreal forest, eastern deciduous forest, and oak and pine savanna, while wetlands are also common throughout the park. The rivers themselves, and the riparian zones along them, greatly influence the biotic communities. The park is divided into two distinct management zones: the upper St. Croix and Namekagon Rivers, and the lower St. Croix River. Numerous private, state, county, and other federal landowners along the corridor make management of access and resource use complex.

Sleeping Bear Dunes National Lakeshore (SLBE) protects 28,813 hectares of land and water along the northeastern shore of Lake Michigan. The lakeshore includes two large islands in Lake Michigan: North and South Manitou. There are 169 kilometers of Lake Michigan shoreline, 26 inland lakes, and four streams. The interior forested areas were dominated by both sugar maple (*Acer saccharinum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.), although the latter species has experienced significant declines due to the impact of beech bark disease over the previous fifteen years.

Voyageurs National Park (VOYA) is located approximately 480 km north of Minneapolis, Minnesota, in the forested lake region along the Minnesota-Ontario border. Voyageurs is composed of 88,243 hectares, of which approximately 33,908 hectares (38%) are covered by lakes and ponds. Two large reservoirs, with hundreds of islands, form much of the lake area, but there are 26 smaller lakes and hundreds of beaver ponds and drainage systems. The interior of the park is typical southern boreal spruce-fir forest, but deciduous trees dominate some areas.

Current Threats to Vegetation in NPS Units

The forests of the Great Lakes Network parks are now heavily impacted by a number of direct and indirect stressors. Direct stressors include several invasive insect pests that are now present at most network parks. These include beech scale (*Cryptococcus fagisuga*), a key causal agent of beech bark disease, which is now present throughout the range of beech within the network. As of 2023, all beech forests in network parks are now in the aftermath phase of beech bark disease. The emerald

ash borer (*Agrilus planipennis*) was first reported near Detroit, Michigan, in 2002 (Muirhead et al. 2006) and, as of 2023, has been confirmed at APIS, INDU, MISS, SACN, and SLBE. This insect is lethal to all North American species of ash; it is not known how the surrounding vegetation will respond following this decline. Spongy moth (*Lymantria dispar*) is now present in six network parks (APIS, SLBE, PIRO, INDU, SACN, ISRO). Like emerald ash borer, this species will likely reach the remaining parks in the next few years. Hemlock wooly adelgid has been slowly spreading from eastern Virginia, where it was discovered in 1951. In 2021, this reached SLBE, the first GLKN park to document its presence. Park staff located it during pest-scouting surveys of high-use areas and removed the infestation. Nonetheless, the main wave of this invasive pest will eventually reach SLBE, PIRO, and APIS, the three network parks with significant hemlock resources. Finally, oak wilt is now present in five network parks. The effects of this are expected to be particularly severe at INDU and SLBE, which host several oak species, covering large regions of the parks.

Earthworms are another group of exotic pests adversely impacting the forests of the upper Midwest. Earthworms are believed to have been absent from areas directly affected by the Pleistocene glaciations, an expanse that includes all network parks (Hendrix and Bohlen 2002). Although natural earthworm dispersion is relatively slow, on the order of 5–10 meters per year (Marinissen and van den Bosch 1992, Dymond et al. 1997, Hale and Host 2005), the introduction of earthworms by anthropogenic means (fishing, horticulture, vermicomposting) greatly augments their spread into previously worm-free areas (Moore et al. 2018). Exotic European earthworms are now present in all Great Lakes Network parks, while Asian earthworms, a newer threat to network parks, are not yet known to be present in any. Both groups rapidly change soil properties by removing the forest floor duff layer (Hale 2004) and by reducing regeneration (Kostel-Hughes 1995).

In addition to exotic species, changes in management and land use have led to uncharacteristic expansion of a few native taxa, such that they have become problem species. The most notable example of this is the irruption of the native white-tailed deer population. Browsing pressure by deer has reduced the abundance of certain native plant species such as Canada yew (*Taxus canadensis* Marsh.) (Windels and Flaspohler 2014), eastern hemlock (*Tsuga canadensis* (L.) Carriére) (Alverson et al. 2019), and many broad-leaved forest wildflower species to a fraction of their previous abundance (Rooney 2001, Russell et al. 2001). Further, overbrowsing by deer is driving change at the community level by promoting the biotic homogenization of Great Lakes forests (Rooney et al. 2004). For these reasons, white-tailed deer is the major problem vertebrate threatening the health of Great Lakes forests.

While direct stressors impart obvious identifiable change to forest structure, indirect stressors can be equally detrimental. This is especially true because the change occurs in a subtle manner over time and causal agents are often not easily identifiable so that reversing this trend is difficult. Regionally, mesophication is occurring where communities are subjected to less frequent fires than occurred historically (Nowacki and Abrams 2008, Hanberry et al. 2012). Here, community dominance shifts away from oaks (*Quercus* spp. L) and pines (*Pinus* spp. L.) to more mesic species, such as red maple (*Acer rubrum* L.). Further, long-term decline of hemlock (Kizlinski et al. 2002, Hanavan et al. 2015)

also poses problems to the health of Great Lakes forests. Here, multiple causal agents are believed to contribute to the decline (Abella 2018).

Finally, the slow, long-term, directional changes in forest composition and structure due to climate change is one of the largest threats facing network forests. Network forests are especially vulnerable because many parks are located at or near the northern hardwood-boreal forest boundary. Here, subtle changes in climate variables can result in disproportionately large changes in species distributions (De Jager et al. 2020). Whether these changes occur gradually, facilitating the coexistence of species cohorts, or as punctuated events following major disturbance, may influence the integrity of park forests.

Routine monitoring of forest health will provide an understanding of natural variability of vegetation in "benchmark" areas where direct human disturbance (e.g., logging, development) no longer occurs. In addition, monitoring will provide an early warning of undesirable trends in vegetation, allow adaptive management of forest ecosystems, and allow for inferences about the effects of the above threats on both terrestrial vegetation and overall forest health.

Overview of Vegetation Monitoring at the Great Lakes Network Parks

This protocol is intended to detail a comprehensive monitoring program with consistent methods across all nine network parks. Significant prior terrestrial vegetation monitoring efforts have been undertaken at five of the network parks, although the duration, extent, and scientific credibility have varied immensely among these efforts.

Permanent forest monitoring plots were established in 1997 on four islands at the Apostle Islands National Lakeshore (Meeker 2000). Although these sites have been permanently marked, regular monitoring has not occurred since initial assessments in 1997–1998. In addition to Meeker's work, Beals and Cottam (1960) established 75 vegetation survey plots on the islands from 1955 to 1958. While these were not intended to be long-term monitoring points, 28 of these plots were revisited in 2005 to assess 47-year vegetation changes (Mudrak et al. 2009). Other vegetation monitoring projects in the park include wetland vegetation (Meeker 2011), Canada yew (Sizer and Johnson 2014, Johnson et al. 2021), rare arctic disjuncts (Johnson 2021b), and fire and vegetation history of the Stockton Island tombolo (Booth et al. 2021).

At Grand Portage National Monument, a system of permanent vegetation plots was established in 1986 to compare changes over time between interior forests and forests adjacent to clear cuts. Metrics for this study were remeasured in 1992, 1999, and 2004 and an analysis of these data was published in 2005 (MacLean and Gucciardo 2005).

Indiana Dunes National Park is one of the most botanically diverse national park units, located at the juncture of prairie, lake, and forest biomes. Approximately 30% of Indiana's state-listed rare plant species occur within the park boundaries (Gucciardo et al. 2005). Not surprisingly, much of the monitoring at the park has focused on rare plant species (Dollard Jr. and Carrington 2013), although impacts of deer browse have also been looked at (Pavlovic et al. 2014).

Isle Royale National Park has the longest history of vegetation monitoring of any of the network parks. In 1963, Peter Jordan of the University of Minnesota established plots to monitor the impact of moose on vegetation (Sell 2007). Other notable monitoring of the island's flora includes assessments of rare arctic and alpine disjunct species by Emmet Judziewicz in 1993–1994, 1998, and 2003. This project has been revisited in recent years (Sanders et al. 2020) and is now led by Sarah Johnson of Northland College.

At Pictured Rocks National Lakeshore, 146 permanent plots were established over the five-year period from 2000 to 2004. The plots were established following the guidelines of the U.S. Forest Service's Forest Inventory and Analysis (FIA) program (Bechtold and Scott 2005), and metrics included all of those in the FIA Phase II program as well as select indices of vegetation and down woody materials that are part of the Phase III program.

The questions addressed by these studies vary, although none have focused on quantifying forest change in response to long-term environmental change. Further, these studies were limited in scope and no attempts were made to integrate the results with other ecosystem attributes such as soils, insects, or mammals. Doing so will allow us to show associations between vegetation and associated attributes. Collectively, a network-wide monitoring system with clear objectives can answer questions about shifts in forest characteristics in response to increasing environmental pressures, as well as provide an assessment of overall forest health.

Measurable Objectives

The goals of this monitoring program are to detect forest change and to draw inferences about forest health so that management recommendations can be provided to the parks. To accomplish this, we take a comprehensive approach, with the monitoring objectives covering species, communities, and other ecosystem components. These are outlined, below:

1. What is the rate and direction of change of key species? We will measure species abundance (e.g., density, frequency) and size (basal area, height) of important species and test for change between and among sample periods. This will allow us to determine whether metrics of individual species are increasing, in decline, or remaining constant. Although assessing change of individual species can be informative, data about plant communities can provide a broader assessment of change.
2. Are plant communities changing? There are numerous ways to assess plant communities and the options chosen will depend on the data available and the exact needs. Options include univariate tests of richness and diversity indices and tests for shifts in the relative abundance of species groups (e.g., native vs. non-native species ratio). Multivariate options include determining whether biotic homogenization (Olden and Rooney 2006) is occurring and using structural equation modeling to relate change to drivers and stressors.
3. Is plant community structure changing and, if so, how? Community structure includes regeneration and succession. We will examine the size distributions of all trees, as well as individual species to identify shifts in forest structure. We will also test for change in small size classes of trees, both for individual species and pooled across all species. This will help

us understand both regeneration and succession. It will also allow us to infer potential drivers of change and, thus, potential threats to the biotic integrity of the Great Lakes parks. We are also interested in learning how non-flora ecosystem components may be impacting vegetation.

4. How are ungulates impacting herbaceous and woody terrestrial vegetation? We will test for change in presence, abundance, and height of herbaceous species that are preferred browse for ungulates. We will also examine woody species for direct evidence of browse (i.e., bite marks) to make inferences about woody species preferences and general degree of browsing pressure.
5. Which pests and pathogens are present on trees and to what extent are they damaging them? We will look for signs and symptoms of major pests and pathogens and quantify the severity of their impacts.

The GLKN forest vegetation monitoring program uses an evidence-based approach. We look for signs of disease presence (e.g., cankers, mycelial fans) or damage (e.g., insect exit holes, leaf mining) and quantify or qualify this based on the category of disease or damage. The actual causal agent (e.g., anthracnose, emerald ash borer) will only be identified if the field sampler is completely certain of it. With instances of repeated and/or widespread disease or damage, samples are collected and submitted to experts for confirmation of the causal agent. For complete methods and analyses for monitoring terrestrial pests and pathogens, please see Standard Operating Procedure (SOP) 8.

Overall Sampling Design

Rationale for Selecting This Sampling Design Over Others

We selected sampling sites using a generalized random-tessellation stratified (GRTS) design (Stevens and Olsen 2004). The reasons for selecting the GRTS design were twofold. First, resulting sample points are spatially balanced, whereby there is a generally even dispersion of sampling sites over the area of interest. This eliminates potential autocorrelation problems that can arise when two or more sampling points are in close proximity (Stevens and Olsen 2000), while also ensuring that all areas within the sampling frame are represented. In addition, the GRTS design allows for sites to be added to or excluded from the original sampling plan, while still maintaining the spatial balance of the overall design. This is important because it is difficult to gauge exactly how many plots can be sampled within a given time period. The second asset of the GRTS method is that it is a probabilistic sampling design, whereby sampling points are randomly chosen from among those in a systematic grid, eliminating site selection bias (Stevens and Olsen 2004). One drawback with any random design is that it does not guarantee that plots will be located in areas of key management significance.

Sampling Frame, Plot Design, and Metrics

The sampling frame for this protocol includes all federally owned lands within the network parks (Table 2). In addition to federally owned land, the sampling frame contains partner-owned land at the Mississippi National River and Recreation Area. At this park, federal land represents only approximately 1% of the acreage, with partner land composing the rest. Finally, some state and private land is included in the sampling frame at Pictured Rocks National Lakeshore. Here, the park is divided into the federally owned "core" area, which directly borders Lake Superior, and the "inland buffer zone," which is composed largely of land owned by the State of Michigan and private entities. At PIRO, the sampling frame includes both the core and inland buffer zones. Sampling points were selected from the entire spatial extent of forested areas in the sampling frame.

Table 2. Sampling frame for each of the nine GLKN parks. Within these defined frames, sampling will also be restricted to forested areas. Inholdings are excluded.

Park	Sampling Frame
APIS	Entire park
GRPO	Entire park
INDU	Entire park
ISRO	Entire park
MISS	Entire park, including both federally owned and partner-owned land.
PIRO	Entire core area of the park and areas of the inland buffer zone owned by the State of Michigan and both commercial and non-commercial private entities.
SACN	All land owned in fee title by either the National Park Service or another agency. This equals 61% of the designated Riverway.
SLBE	Entire park
VOYA	Entire park

This protocol details our plans to monitor forested vegetation. We have adopted guidelines consistent with those of the U.S. Forest Service FIA program (U. S. Department of Agriculture 2005) to define what constitutes a "forest," whereby there is a 10% minimum stocking requirement of tree species. The 10% requirement denotes that the site can either have at least 10% canopy cover at the time of sampling or will likely return to that percentage in the future. As such, areas experiencing a recent burn or blowdown are included, as are previously managed grasslands now returning to the forested state. Tree species are defined *a priori* and include, for example, some "shrubby" species such as striped maple (*Acer pensylvanicum* L.) and paw paw (*Asimina triloba* [L.] Dunal), but not others such as speckled alder (*Alnus incana* [L.] Moench ssp. *rugosa* [Du Roi]). Based on these guidelines, habitats such as oak savannas and tamarack bogs are included, while alder swamps are not.

Sample sites were selected using the GRTS method described above. While this approach uses spatial stratification to ensure that sample sites are equally distributed within the sampling frame, we did not stratify on vegetation type. The successional nature of vegetation, coupled with the fact that much of the forested areas in the network are recovering from logging activity that occurred prior to establishment of the parks, precludes the use of stratification. Stratifying on a dynamic variable, such as vegetation, will ultimately result in misclassification of sites and consequent analytical error. Further, a stratified sampling design will prevent inferences about those vegetation types not sampled (DeBacker and Morrison, unpublished data).

Although stratification on a dynamic variable was avoided, it is acceptable to stratify based on a non-changing characteristic. For example, sites at PIRO and SLBE were stratified so that 10% of the plots would occur on sandy, nutrient-poor soils. As soil condition is only expected to change on the order of millennia, this practice is statistically valid.

Parks within the Great Lakes Network will use a plot design developed specifically for the Great Lakes I&M Network's long-term vegetation monitoring protocol. This design combines features from two established plots types: the FIA plot (Bechtold and Scott 2005), currently used throughout the country by the U.S. Forest Service, and the Plant Ecology Lab (PEL) plot developed by John Curtis and used extensively in the upper Midwest throughout the 1950s and 1960s (Curtis 1959). Consequently, the Great Lakes Network's design has been designated the "hybrid plot" (Johnson et al. 2006, 2008).

The hybrid plot consists of three parallel, 50-m, east-west transects, spaced 50 meters apart (Figure 2). The species and diameter at breast height (DBH) of all trees ≥2.5 cm DBH are recorded in a 6-m-wide belt around each transect (3 m on either side of center line; Figure 2, left). Because we are using 2.5 cm as the lower DBH limit, we are thus including "trees" (≥12.7 cm DBH in FIA standards) *and* "saplings" (≥2.5 cm and <12.7 cm DBH) within this area. Any evident damage from pests and pathogens or abiotic factors is noted for each tree measured. Coarse woody materials are also assessed along each of these three transects, whereby data are collected on all downed wood that intersects the transect plane having a diameter of ≥7.5 cm at the point of intersection.

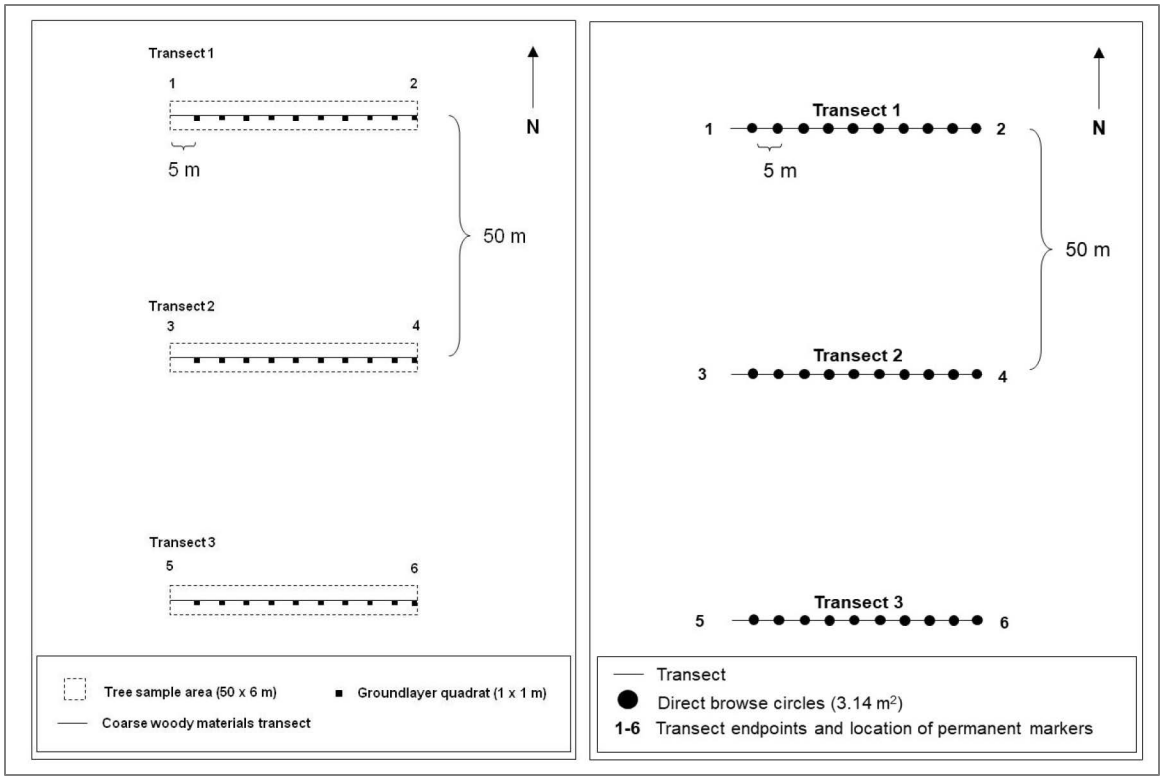


Figure 2. Left: scale diagram of the hybrid plot, showing three parallel belt transects and areas for data collection of tree, groundlayer, and coarse woody material metrics. Right: hybrid plot showing where direct browse and shrub data are collected.

The groundlayer is assessed in 1 × 1 m quadrats spaced every 5 meters along each of the transects for a total of 30 quadrats in each plot (see Figure 2, left). We record all herbaceous and shrub species present in each quadrat so that they can be quantified by their frequency of presence in each plot. We feel this is a better method for quantifying abundance than percentage of cover, which is subject to observer bias and varies throughout the growing season. We also prefer frequencies to direct counts of herbaceous individuals. Even in 1-m^2 quadrats, dozens (and even hundreds) of herbaceous individuals of a given species can exist, making exact counts questionable. Despite the problems associated with direct counts of herbaceous species in the 1-m^2 quadrats, seedlings of woody species are not as abundant, and their upright growth habit makes counting these practical. Therefore, seedling (<2.5 cm DBH and ≥15 cm tall and exhibiting second-year growth) densities are determined by counts within the 1-m^2 groundlayer quadrats.

Ungulate browse is assessed via two means. First, we assess browse on each woody species in each of 30 one-meter radius (3.14-m^2) browse circles (see Figure 2, right). These are centered every five meters along each of the three transects. We refer to this as "direct browse" because we are quantifying bite marks, which are directly visible on the plants. We also quantify browse by changes in the frequency and height of key herbaceous species. We refer to this as "indirect browse" since evidence is only indirectly observed as changes in abundance or stature over time. We measure the height of the tallest individual of key species in each quadrat. Beyond this, however, no additional

data collection for indirect browse is needed because we assess the abundance of these key species via frequencies obtained with the groundlayer data. As with herbs, shrubs are assessed as a frequency of presence (see Figure 2, right). We will use the presence data from the direct browse assessment to obtain these frequencies.

We have permanently monumented all sites by sinking a 30-cm piece of rebar flush into the ground at each of the six transect endpoints. We also placed yellow plastic end caps on the ends of rebar pieces to facilitate relocation. At each transect endpoint, we tag three nearby living trees, collectively referred to as "reference objects," using a nail and numbered aluminum tag and record the distance and bearing from each reference object to the rebar. We have developed procedures for situations where it is not possible to sink rebar exactly at the transect endpoint; these are detailed in SOP 5: Plot Establishment. In no case is plot marking noticeable from a trail or other public area. Where this would be the case, we develop suitable alternative methods for each unique situation; these involve eliminating the yellow end cap and placing the aluminum tag on the opposite side of the trees. During the second sampling round in each park, we used a mapping grade GPS (Trimble) to collect a minimum of 120 sets of coordinates at each endpoint. All plots are relocated with the aid of a metal detector, GPS, and map showing the permanently marked endpoints.

Sampling Frequency, Replication, and Timing

Vegetation monitoring is conducted on a rotation, generally with one park visited each year (Table 3). While we initially planned a five-year rotation, with smaller and mid-sized parks sampled together in some years, we found that this did not allow enough time to complete the desired number of sites. All sites are resampled during each visit to a given park. We feel that doing this approximately once every nine years is a good balance between sampling too frequently, where trampling of the site can adversely impact the plant community, and sampling too intermittently, which reduces the ability to detect change over a given time period. Sampling at nine-year intervals allows time for some change to occur, yet provides relatively frequent feedback to park natural resource managers about long-term directional change. We concede that an ideal scenario is to visit one ninth of the plots in each park each year. Thus, the plots at any given park would be sampled throughout the nine-year rotation. While this would capture inter-annual variation and better assess the impact of cyclic insects and/or disease cycles, this scenario is both logistically and financially infeasible. Table 3 shows the years each park was sampled during the first two rotations and the planned third rotation.

Table 3. Schedule for the first two monitoring rotations at each park and the planned year for the third monitoring rotation. No field work was done in 2020 due to the COVID-19 pandemic.

	Sampling Round		
Park	**1**	**2**	**3**
INDU	2007	2012	2023
SACN	2007	2013	2024
GRPO	2007	2014	2025
VOYA	2008	2015–2016	2026
PIRO	2009	2017	2027
SLBE	2009	2018	2028
ISRO	2010	2019	2029
APIS	2011	2021	2030
MISS	2011	2022	2031

Recommended Number of Sampling Sites and Frequency

The division of sampling effort between the parks was originally determined by both top-down and bottom-up approaches. For the top-down approach, the forested acreage in each park was used as the basis for a preliminary estimate of the number of sites in that park. The bottom-up approach used statistical power analyses to estimate the total number of sites needed to detect change, given a desired power level (Johnson et al. 2006, 2008). The target of the GLKN monitoring program is to be able to detect a 20% change in metrics over a given time period with 80% power and $\alpha = 0.1$ (Fancy et al. 2009). Drawing on both approaches, we targeted a certain number of sites in each park, while also factoring in logistics and accessibility. Ultimately, the power to detect change will vary by metric and park, but the number of sites selected is expected to provide a relatively high amount of power for many of the desired indices.

Sample Method Selection and Level of Change That Can Be Detected

In a direct assessment of the hybrid plot design, data from 20 sites showed that there was greater than 99% power to detect a 20% change in both tree basal area and tree density between sampling events (Johnson et al. 2006). For herbaceous species, the hybrid plot design had greater than 80% power to detect changes in fern frequency and forb species richness (87.2% and 89.9%, respectively) between sampling events (Johnson et al. 2006). Clearly, the number of active sites in each park (Table 4) should be sufficient to be able to detect a 20% change in metrics over a given time period with 80% power and $\alpha = 0.1$. However, we will rarely (if ever) group all sites within a park together for an analysis. Forest types will respond uniquely to environmental stressors and change. We will likely extract data from subsets of plots for any analysis of change. While it is not possible to know how many plots will be needed to detect the desired level of change, it should be assumed that fewer than 20 plots per grouping will result in less power than that detailed in the study above.

Table 4. Sampling effort in each park in relation to sampling area available.

Park	Forested area (hectares)	Percentage of total network forested area	Number of sites	Percentage of total network sites
APIS	17,037	7.75	50	11.24
GRPO	281	0.13	23	5.17
INDU	6,095	2.77	50	11.24
ISRO	53,823	24.48	60	13.48
MISS	5,581	8.99	50	11.24
PIRO	24,724	11.25	59	13.23
SACN	26,828	12.20	50	11.24
SLBE	25,981	11.82	50	11.24
VOYA	45,325	20.61	53	11.91
Total	219,862	100.00	445	100.00

Field Methods

Field Season Preparations and Equipment Setup

Preparations for the field season are numerous and must begin before the calendar year. Many of these preparations will necessarily overlap with the duties associated with concluding the previous season, such as report writing (see SOP #13, Procedures after the Field Season). Because of these demands, meticulous care must be taken to ensure all pre-season procedures are followed in a timely manner.

Early pre-season preparations (October–February) are primarily of an administrative nature. The vegetation monitoring budget (and, therefore, the schedule) must be developed by early October, as it is a component of the general GLKN budget. Position announcements for seasonal employees are distributed in early December and interviews begin in early February. Also during the fall, the park where the GLKN field crew will be working should be contacted and needs for office space and IT should be addressed. The project manager should also make park managers aware of other needs such as park housing and boat transportation. Once this schedule is finalized, the project budget for the season should be refined. At this point, arrangements should be made for any needed training for the crew members, including boat operation and first aid. Once these details are finalized, the project manager should apply for a research permit in the park where the field crew will be working.

Later pre-season preparations (March–April) focus on equipment preparation and field readiness. The equipment list should be reviewed, and all equipment should be inspected, with repairs made and new equipment ordered as needed. This includes checking all tapes for worn parts, assembling tents to look for torn material, checking backpacks, and inspecting personal protective equipment. In addition to equipment, data collection procedures should be readied. Plot coordinates and digital park maps should be loaded into the field GPS units, and paper park maps should be obtained and notated if needed. The plant lists for the park should be reviewed and printed, with taxonomy changes addressed at this time.

Sequence of Events During Field Season

Seasonal crew members begin work between mid-May and early June, depending on the park. The initial three-week period focuses entirely on training. This training is extensive and includes both an administrative and field component. Administrative work includes mandatory, computer-based federal IT training. Field-focused training includes plant identification and all aspects of plot establishment and training. It also includes the use of all electronics and similar devices (e.g., Garmin GPS units, park radios, tablets, satellite messengers). During the training period, we also stress work etiquette, interacting with other park employees, and how to answer questions from the public about the work we do. All field crew members will be required to pass a check test for both sampling techniques and use of electronics before sampling can begin.

The field crew (excluding the Terrestrial Ecologist and Botanist) will be duty-stationed at the park where they are sampling. Throughout the field season, the field crew, along with the Terrestrial Ecologist and/or Botanist, will work a schedule of eight consecutive 10-hour days, followed by six

days off. This schedule will accommodate travel time between the GLKN office and the parks by the Terrestrial Ecologist and/or Botanist, allowing them to accomplish necessary administrative duties at the network office. Although there is not a great deal of flexibility in the schedule, there are a sufficient number of uncommitted days in the sampling schedule at all parks, during which any sampling that was missed (e.g., due to weather or illness) could be made up.

Details of Taking Measurements

We follow many of the same measurement criteria and standards as the FIA program. This includes details such as how to measure forking trees and how to treat leaning or down live trees. For more details on this, refer to the Forest Service Phase 2 Field Guide (U.S. Department of Agriculture 2005) and SOP 6: Field Methods and Data Collection. This approach allows comparability between data collected using the GLKN hybrid plot with that collected by the FIA program in the area surrounding the parks, provided appropriate statistical measures are taken to account for differences in plot area and sample size. All data are entered into tablets using customized field forms. Standard paper field forms printed on Rite-in-the-Rain® paper are carried to the site as a backup.

Post-Collection Processing of Samples

The nature of this protocol is such that there are minimal samples collected. One exception to this is when unknown plant specimens are collected for identification. When this occurs, the field crew will be responsible for following established guidelines for collecting, labeling, photographing, and transporting it for later identification. For more detail on this, see SOP 7: Procedures for Handling Unknown Species.

End-of-Season Procedures

The procedures associated with completing the sampling season must be performed in earnest in the weeks immediately following the conclusion of sampling, then continued through the following April. Early post-field season procedures focus on administrative tasks; equipment inspection, repair, and organization; and data archival procedures. Immediately following the completion of sampling, field equipment should be inspected, cleaned, and repaired as needed, and notes should be made as to what needs to be replaced. Throughout the month of September, data archival procedures should be carried out and park species lists updated with new records.

Data Handling, Analysis, and Reporting

Overview of Database Design

The GLKN vegetation monitoring database is an MS Access database consisting of both front-end and back-end components. The network maintains the master copy of the vegetation database on the office server (the "production database"), which is the only copy from which data can be exported to other locations. We also maintain a developmental copy of the front-end, which is used when making and testing modifications. Additional local copies of the database may be made available on work computers of GLKN personnel as a conduit for data entry and/or analysis.

Data Collection, Entry, and Editing

We use ruggedized tablets to record data when in the field, although paper datasheets are carried as a backup measure. Data are typically collected by a team of two samplers, with one crew member recording data primarily on overstory trees and coarse woody material and the other documenting herbaceous species and browse. The tablets are typically backed up at the end of each eight-day sampling period. If datasheets are used, these are photocopied and the data entered at the earliest possible time. The datasheets are later checked for accuracy of data entered and archived in the central office.

Metadata Procedures

Metadata allows potential data users to evaluate the quality and usefulness of the data based on an understanding of the complete process under which it was collected and maintained.

Metadata for all analysis datasets will be created using the Ecological Metadata Language standard (EML). The R package, EMLassemblyline, will be used to automate the creation of metadata for inclusion in all published data packages. EMLassemblyline processes a series of CSV files that outline all the relevant metadata for each data package and generates an XML metadata file. Wherever possible, the metadata included in the source CSV files will be extracted directly from the production database. This process will also detail information about protocol versions used to collect the data.

Data that are generated and/or managed outside of I&M but used in analyses with GLKN data or distributed in any manner by the NPS, require the same level of documentation as GLKN-generated data. This includes data produced under contract with the NPS. For non-program data, the project manager will ask the originating entity for metadata. Any contract or agreement entered into by GLKN with data producers will require FGDC-compliant metadata in HTML, ASCII, XML, or in a different format specified by the project manager. (FGDC is the Federal Geographic Data Committee.) The network data manager will assist the project manager in metadata acquisition by providing tools, format protocols, and file transfer services.

Recommendations for Data Summaries and Analyses and Reporting Schedule

We use two primary avenues for reporting. Through the first and second round of sampling in parks, we produced annual summary reports for the park(s) monitored during the previous year. The

primary audience for the annual summary reports has been park managers. Beginning with the third sampling round, we compile data so that these summaries can be pulled and viewed via an interactive visualizer integrated into the network's website. These summaries graphically display metrics of interest (e.g., species richness, tree density) across all sampling events in a park and provide context about potential changes occurring.

In addition to summaries, detailed reports in which data are analyzed are produced on a periodic basis. These are written as manuscripts intended for submission to peer-reviewed journals and contain in-depth analyses on a topic or limited suite of topics relevant to park management. Further, these manuscripts place the findings in both a regional and historical context by relating them to other published literature, discuss the significance of the results in terms of environmental change, and provide management recommendations based on the findings. More details about reporting are presented in SOP 11: Data Summary and Analysis and SOP 12: Reporting.

Recommended Methods for Analysis

Upon the third sampling event in a park (see Table 3), we will be able to test for trends. This will be accomplished through a number of statistical means, but primarily via linear models. Although trends can be informative, other types of analyses are likely as valuable, if not more so. Notably, multivariate techniques can also shed light on changes that are happening in the parks, providing visual displays of this change, which can aid in informing management. The actual analyses performed will depend on the park, problems in that park, and availability of supporting data. Refer to Standard Operating Procedure 11: Data Summary and Analysis for more details.

Data Archival Procedures

Vegetation monitoring data is maintained in a Microsoft Access database stored on the network server. Copies of the database are also stored on a removable disk backup system and updated via delta copying on a regular (daily-to-weekly) basis. One backup copy is stored offsite at all times. Finally, at key milestones in the annual data life cycle (e.g., after data entry, quality control checks), the database is copied to an external hard drive, which is stored in a fireproof safe at the network office.

Personnel Requirements and Training

Roles and Responsibilities

The project manager (Terrestrial Ecologist) for this protocol is a liaison between the permanent network staff, seasonal network staff, and the parks. The project manager is charged with organization and facilitation of all aspects of the long-term vegetation monitoring protocol. This includes the following:

- Taking the lead in hiring seasonal staff
- Developing an annual field schedule
- Acquiring the appropriate permits (e.g., research and collecting, camping)
- Arranging training (e.g., first aid, CPR)
- Refining the budget for the season
- Ushering crew members through administrative training
- Co-supervision of seasonal staff during field season
- Identifying plants accurately and processing unknown plants for later identification
- Ensuring plot work meets the desired quality standards
- Working with Botanist to ensure an adequate number of sites are sampled at each park
- Ensuring effective communication between park staff, the field crew, and other GLKN staff
- Onboarding, offboarding, and performance reviews for seasonal field crew members
- Reviewing and revising the protocol
- Data analysis and report writing
- Presenting findings to the technical committee and other entities

The Botanist is responsible for field aspects of monitoring as well as leading all aspects of data transfer. The Botanist is also responsible for co-supervision, along with the project manager, of the seasonal staff. Specific duties include:

- Preparing, repairing, and purchasing equipment
- Preparing the database for the upcoming season (e.g., review species lists, add names of seasonals)
- Developing GIS maps pre-season for navigation to plots and post-season for archival purposes
- Identifying plants accurately and processing unknown plants for later identification
- Ensuring plot work meets the desired quality standards
- Collection of plot data

- Scheduling and timekeeping for seasonals
- Ensuring equipment is clean and functional prior to each trip
- Ensuring all needed equipment is collected and readied prior to each trip
- Interacting with park staff as needed to organize transportation and equipment needs
- Data quality assurance/quality control checks (QA/QC)

The seasonal staff are responsible for day-to-day completion of plot establishment and monitoring. Specific duties include:

- Completion of mandatory training including first aid, boat/canoe training, and plot establishment
- Assisting with navigation to sampling points
- Identifying plants accurately and processing unknown plants for later identification
- Ensuring plot work meets the desired quality standards
- Collection of plot data
- Ensuring equipment is clean and functional prior to each trip
- Ensuring all needed equipment is collected and readied prior to each trip

Crew Qualifications

The project manager must have an advanced degree in botany, plant science, or biological science with an emphasis in plants. They should also have demonstrated experience identifying the flora of the Great Lakes and surrounding region, acquired through a combination of work experience, education (graduate school research), and/or workshops and other training. The project manager must also have a minimum of one year experience leading a field crew.

In addition to botanical and leadership skills, the project manager must be knowledgeable about multiple aspects of forest health. This includes knowledge of common forest pests and pathogens and an awareness of future threats. Finally, the project manager must have experience in vegetation data analysis and reporting.

The Botanist will co-supervise the seasonal employees, along with the project manager. The Botanist must have at least a four-year degree in botany, plant science, or biological science and have at least one year of vegetation-based work experience equivalent to the GS-6 level. Alternatively, the Botanist may have an advanced degree with an emphasis in vegetation. The Botanist must also have at least one season (three months) of experience supervising field personnel and have demonstrated experience (work or education) identifying flora of the Great Lakes region. Finally, they must demonstrate the ability to navigate with map, compass, and GPS.

The seasonal employees must be working toward, or already possess, a four-year degree in biology, botany, natural resources, environmental science, forestry, or related major. These employees must

also have demonstrated experience (work or education) identifying either overstory or understory vegetation of the region.

All people on the crew (Terrestrial Ecologist, Botanist, and seasonals) must be physically fit and able to work in adverse environments. This includes working in extreme heat and cold, and in the presence of biting/stinging insects and poisonous plants.

Training

The Terrestrial Ecologist and Botanist are expected to attend regular training opportunities to further their ability to oversee the vegetation monitoring program. These can include, but are not limited to, statistical courses, botanical and ecological trainings, and related conferences, workshops, and seminars.

The seasonal field crew starts in late May or early June. During the three-week training period, they will undergo training in administrative procedures, plant identification, plot establishment, data collection, data entry, and first aid/CPR. They will also learn proper use of all electronics and radios.

Administrative training procedures are performed over the first two days of employment. This will cover issues associated with performance, computer use, and reporting time. This training will be provided by the Terrestrial Ecologist and Botanist.

The bulk of the three-week training time will be devoted to multiple aspects of vegetation monitoring. The seasonal employees will be instructed on how to establish the sampling plots, with emphasis placed on the high degree of accuracy required with the distances, bearings, and metrics measured. During this time, the crew will also be instructed on use of all electronics, including tablets for on-site data collection. During training, the crew members will also familiarize themselves with the vegetation of the park in which they are working. Plants that are encountered but cannot be readily identified during this time will be learned so that, when they are encountered in actual plots, they can be quickly identified. This training will be provided by the Terrestrial Ecologist and Botanist.

The crew will also participate in first aid and CPR training during the initial three-week training period. Finally, the crew will be instructed on etiquette for interactions with the general public visiting the parks. The Terrestrial Ecologist and Botanist will explain how to answer questions specifically about their work and the network's work more broadly.

Operational Requirements

Annual Workload and Field Schedule

Employment for the seasonal staff begins between mid-May and early June, depending on the park. The seasonal staff go through an intensive training period, with actual sampling beginning approximately three weeks after the start date. The sampling season then runs through the end of August.

Facility and Equipment Needs

We carry out this protocol in a manner as independent of the parks as possible. Despite this, logistics in general, and boat transportation specifically, remain features for which we need to rely somewhat on parks or other GLKN staff. In addition to boat transportation, we will rely on the parks to, wherever possible, provide housing for the field crew.

At all parks, regardless of whether they are remote or not, we will depend on the park staff for assisting with basic security and safety precautions. In remote parks, each two-person field crew will be equipped with a radio (supplied by the network), and the Terrestrial Ecologist will arrange with the park staff to obtain radio call numbers prior to beginning sampling.

Budget Considerations

The annual operating costs for the vegetation monitoring protocol are estimated to range between $80,000 and $100,000 (excluding salary for the Botanist and Terrestrial Ecologist). The majority of these expenses (approximately 70%) are for salary of the seasonal field crew members.

Besides salary, the other primary expense of the vegetation monitoring program is travel. This includes travels costs (e.g., hotels and meals and incidental expenses [M&IE]) for the Botanist and Terrestrial Ecologist for monitoring as well as training, workshops, and conferences. This typically equals about 20% of the budget, while field supplies (e.g., equipment replacement and repair, plot marking materials) represent approximately 10% of the budget.

Procedures for Revising the Protocol

The long-term nature of the NPS monitoring program necessitates the need for flexibility to incorporate change. Refined field methods, advances in analysis techniques, and feedback from field crews and project managers can all contribute to improving the monitoring protocol. To systematically identify areas and procedures needing revision, we will review the protocol each year at the end of the field season (see SOP 13: Procedures After the Field Season). To minimize the changes to the protocol narrative, we will first attempt to revise SOPs without making changes in the protocol itself. However, if it is clear that changes are also needed on the narrative, then it will also be revised.

All changes will be agreed upon by both the Terrestrial Ecologist and Botanist, and substantial changes (e.g., revised analysis techniques, significantly altered field methods) may also be sent to outside sources for input. Any changes are recorded in the revision history log of the appropriate

SOP and/or narrative. Copies of the revised material are then distributed to all relevant parties and subsequently posted on the network website. Further, the data manager will be notified of the change(s) so that the metadata of the project database can be updated. For a detailed description of protocol revision procedures, please see SOP 14: Revising the Protocol.

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