

Cumberland Piedmont Network

National Park Service
Inventory and Monitoring Division



Standard Operating Procedure 13

Analysis and Reporting—Version 1.1

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Overview

This standard operating procedure (SOP) describes how data collected as part of this project are processed, how ecological integrity is assessed, and how change analysis is conducted using data collected as part of this project.

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Data Collection and Analysis

This section will continue to be edited throughout 2011 and 2012 as we begin data collection and refine our methods for summarizing and analyzing data. The Cumberland Piedmont Network (CUPN) staff will use data collected on quantitative measures to keep track of and report out on statistically significant changes over time in measures park wide. In addition, CUPN staff will use a combination of collected data, models, and expert opinion from literature and personnel to interpret key metrics and choose cutoffs for each metric that assign values of “Good,” “Caution,” and “Significant Concern” for forested ecosystems.

Although we have not yet finalized the details of the approach, Figure 1 broadly illustrates the overall concept behind: (1) developing a scorecard with summary information about each park’s forested communities, and (2) reporting out on change over time in key metrics.

Key Products:

- Summary and Scorecard of Data Collected for Vegetation Communities (published for each park every two years)
- Status Report on Vegetation Communities (published for each park and the network every five years)

Key Tools:

- Statistical package such as R (to be selected in 2011)
- Database (Microsoft Access) – Database core based on the I&M Programs Natural Resource Database Template (NPS 2007)
- Tools for summarizing data

Data Analysis Flow Diagram

Draft 1.0 Wednesday, February 23, 2011

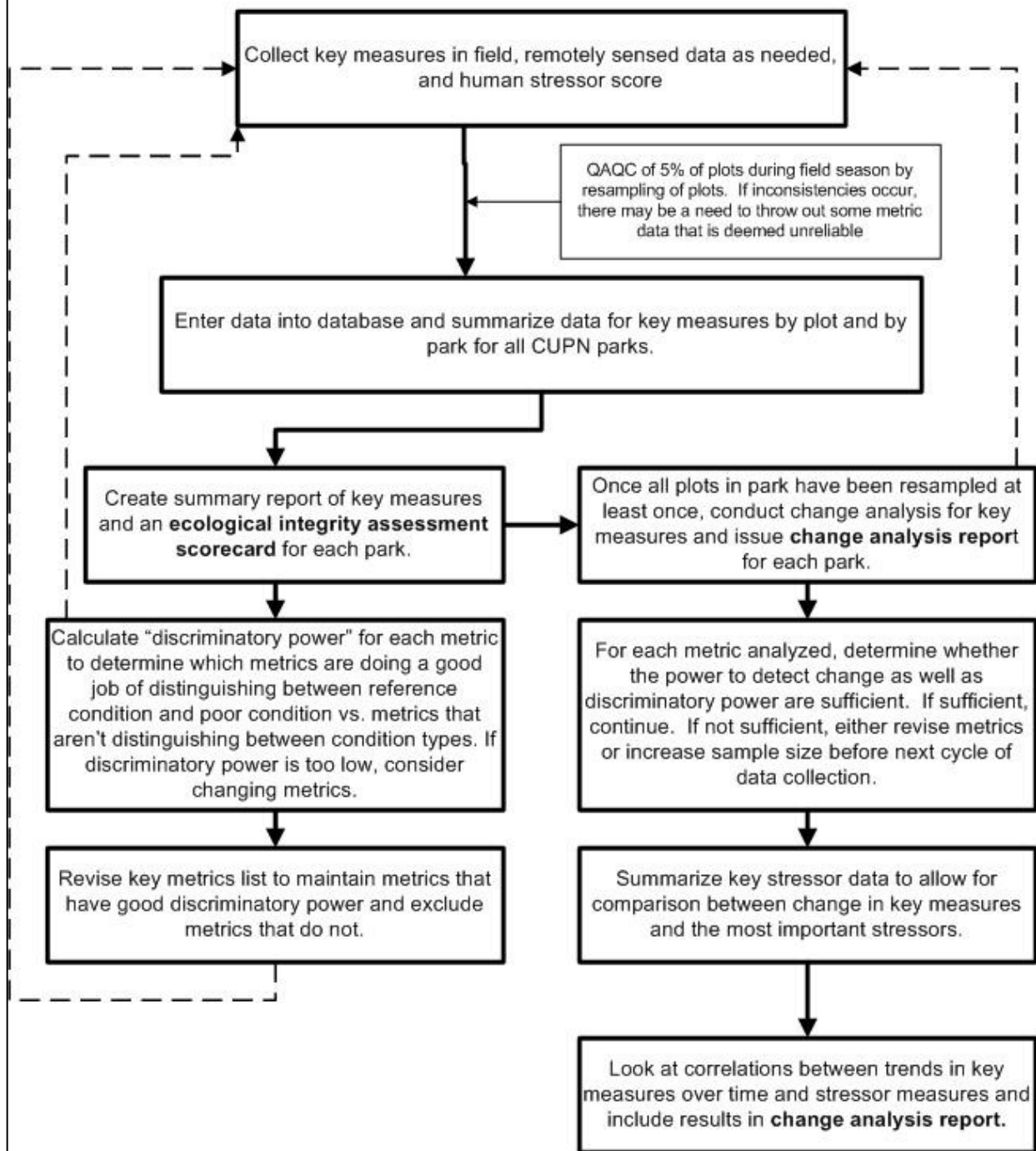


Figure 1. Sample flow chart for handling data summary and analysis for the CUPN vegetation monitoring project.

Ecological Integrity Scorecard and Summary

The specific measures summarized and reported on every two years as part of the scorecard are outlined in this SOP with steps for calculating both the quantitative measures and the EIA (Ecological Integrity Attribute) scores based on acceptable or desired ranges of variation for each metric. Much of this work is based on information received from the Northeast Temperate Network's vegetation monitoring group (Tierney et al. 2009). For the EIA scores, the acceptable or desired ranges of variation have been derived from knowledge of the natural or historical range of variation for each metric, or in some cases, trend towards or away from perceived natural or historic conditions. The interpretation of ecological integrity is a useful but developing conservation application, and ratings should be reviewed and updated as new information becomes available. A scorecard format is outlined in this SOP that may serve to report the integrity of CUPN forests to intended audiences (Table 1).

Table 1. Example of a biannual ecological integrity scorecard for terrestrial forested ecosystem (ratings are only for demonstration purposes)

Metric Type/Ecological Attribute	Metric	Rating for Park
Landscape Context and Size	Landscape Connectivity	Good
	Patch Size	Good
Structure	Vegetation Structure	Caution
	Stocking Index	Good
	CWD Volume	Caution
Composition	Biotic Homogenization / FQI	TBD
	Indicator Exotic Plant Species Richness	Good
	Forest Pest Species Presence	TBD
	Tree Growth and Mortality Rates	TBD
	Soil Chemistry—Acid Stress	Significant Concern
Function	Soil Profile Disturbance and Soil Chemistry	Caution

The concept of “ecological integrity” has been used as a tool to measure the health of ecosystems and the effectiveness of land management actions upon those ecosystems (Karr 1993; Woodley 1993; Tierney et al. 2009). Building upon the related concepts of biological integrity and ecological health, ecological integrity is a broader and more useful conceptual endpoint for ecological assessment and reporting (Czech 2004). “Integrity” is defined as the quality of being unimpaired, sound, whole or complete. To have integrity, an ecosystem should be relatively unimpaired and complete across a range of characteristics and scales (DeLeo and Levin 1997). “An ecological system ... has integrity ... when its dominant ecological characteristics (e.g., elements of composition, structure, function, and

ecological processes) occur within their natural ranges of variation and can withstand and recover from most perturbations imposed by natural environmental dynamics or human disruptions” (Parrish et al. 2003).

Selecting Metrics for Ecological Integrity Attributes

The first step in determining ecological integrity is identifying a limited number of key attributes or metrics of an ecosystem that best differentiate between a highly impacted or degraded state and a relatively unimpaired, complete and functioning state. Key attributes may be properties that typify a particular ecosystem (Keddy and Drummond 1996; Parrish et al. 2003) or attributes that change predictably in response to anthropogenic stressors (Karr and Chu 1999). The suite of attributes selected should be comprehensive enough to incorporate composition, structure and function of an ecosystem across a range of spatial scales (Andreasen et al. 2001).

A conceptual ecological model delineating known linkages between key ecosystem attributes and stressors is a useful tool in identifying and interpreting metrics. The Cumberland Piedmont Network has relied on overarching forest ecosystem models developed in the CUPN Monitoring Plan (Leibfreid et al. 2005) to identify key attributes and stressors and understand agents of change acting upon terrestrial ecosystems (see discussion about stressors in main document). Justification for the selection of each metric is included below within the Metrics and Ratings section.

Rating Metrics

A second step in determining ecological integrity is distinguishing acceptable from undesired condition for each metric. Determination of acceptable versus undesired conditions should consider both current management goals as well as natural or historic variability. The CUPN parks are managed for a variety of values, both cultural (historical) and ecological. For some metrics, it is unrealistic or impossible to expect “natural” ecological condition at these small cultural parks.

However, there are several reasons to consider natural or historic variability in determining acceptable condition. First, estimates of historical or natural variation in ecosystem attributes provide a useful reference for gauging impacts of current anthropogenic stressors. Second, it has been proposed that maintaining historical or natural variation provides a coarse-filter approach for sustaining biological diversity in the absence of full understanding of stressor impacts, particularly on less well-known species (Hunter et al. 1988). Third, management within natural or historic variability often is easier and requires fewer external inputs and unforeseen side effects than management outside the natural bounds of the ecosystem (Allen and Hoekstra 1992). Finally, the concept of natural or historic range variability recognizes the inherent natural variation in ecosystems across space, time and ecological succession and incorporates this variability into the development of acceptable conditions (Landres et al. 1999).

Of course, current knowledge of historic or natural conditions is limited. Insight into natural or historic conditions comes from historical studies and records, paleoecological reconstructions of past conditions, current studies of relatively pristine ecosystems, and efforts to model ecosystem

dynamics. While all these efforts provide useful insight, our understanding of historic or natural conditions in many ecosystems relies on a limited number of key studies, and care must be taken when applying data from these studies to other sites. **For these reasons, ratings should be reviewed and updated as our knowledge of the historic or natural variation and ecosystem response to perturbation increases over time.**

Following the NPS national Vital Signs rating system, three ratings are used: Good, Caution and Significant concern. “Good” represents acceptable or desired conditions; “Caution” indicates a problem may exist; “Significant concern” indicates undesired conditions in need of management correction. For several metrics, we have not defined conditions that merit “significant concern” either because more research is needed, or to provide natural resource managers with greater flexibility to balance the potential conflict between cultural values and ecological integrity at this group of small and primarily cultural parks.

Summary Data and Scorecards

The Cumberland Piedmont Network will use a combination of (1) data summaries of quantitative data and (2) ecological integrity scorecards to clearly and concisely report ecological integrity to a wide audience. A successful ecological scorecard should transparently convey status and trend in key ecological parameters in a way that is meaningful to the public, managers and other stakeholders (Harwell et al. 1999).

We developed a scorecard reporting framework (Table 1) that heavily borrows from the Northeast Temperate Network (NETN) model (Tierney et al. 2009) to visually convey status and trends in each metric of integrity. This symbology uses color to convey integrity rating: Good, Caution and Significant Concern are conveyed respectively as green, yellow or red circles. It uses an embedded arrow to convey the direction of trend observed across sampling intervals (increasing, stable or decreasing). For transparency, actual data values will be reported in addition to ratings.

Metrics and Ratings

Metrics and ratings are summarized in Table 2. The quantitative measures behind these metrics are used both to populate the scorecard/summary for each park and to determine change over time in key measures. The text that follows provides an overview, justification, calculation description, scaling rationale, and suggested level of confidence for each metric.

Table 2. Summary of draft metrics with ratings for CUPN parks (full descriptions of each metric continue below the table).

Type	Metric	Ecosystem	Good Rating	Caution Rating	Significant Concern Rating
Biotic condition	Tree regeneration/deer browse	Forest (Upland and Wetland)	Seedling ratio ≥ 0	Seedling ratio < 0	Stocking index outside acceptable range (< 25)
Biotic condition	Tree growth and mortality	Forest (Upland and Wetland)	Growth $\geq 60\%$ mean and Mort $\leq 1.6\%$	Growth $< 60\%$ or Mort $> 1.6\%$	–
Biotic condition	Tree condition	Forest (Upland and Wetland)	Foliage problem $\leq 10\%$ AND no HWA, BWA, BBD, BC, ALB, EAB, SOD	Foliage problem 10-50% OR HWA, BWA, BBD, BC	Foliage problem $\geq 50\%$ OR ALB, EAB, SOD
Biotic condition	Snag abundance	Forest (Upland and Wetland)	$\geq 10\%$ standing trees are snags and $\geq 10\%$ trees of > 25 cm DBH are snags	$< 10\%$ standing trees are snags OR large snags underrepresented	< 5 med-lg snags/ha
Biotic condition	CWD Volume	Forest (Upland and Wetland)	$\geq 15\%$ live tree volume	$< 15\%$ live tree volume	–
Biotic condition	Biotic homogenization / floristic quality	All	No increasing trend of biotic homogenization and Ave. coefficient of C > 3	Increasing trend of biotic homogenization and avg. coefficient of C between 1.5 and 3	Ave. coefficient of C < 1.5
Biotic condition	Indicator species – invasive exotic plants	All	No high priority invasive exotic species in plot	1 to 3 high priority invasive exotic species in plot or $> 10\%$ relative cover of exotic species in plot.	4 or more high priority invasive exotic species in plot or $> 25\%$ relative cover of plot
Biotic Condition	Stand structural class	Varies by type	Late-successional	Mid-successional	Early successional
Abiotic condition	Soil chemistry (optional)	All	Additional research needed	Additional research needed	Additional research needed
Abiotic condition	Soil layering	All	Additional research needed	Additional research needed	Additional research needed

Type	Metric	Ecosystem	Good Rating	Caution Rating	Significant Concern Rating
Landscape Context	Landscape connectivity	All	Core area (100 ha) and supporting area (1000 ha) are at least 90% non-human influenced.	Core area (100 ha) is 90% “non-human influenced” but supporting area is less than 75% “non-human influenced”	Core area is less than 90% “non-human influenced” or supporting area is less than 75% non-human influenced
Size	Patch size of occurrence	All	> 50 hectares contiguous forest/woodland	1-50 hectare contiguous forest/woodland	Less than 1 hectare contiguous forest/woodland

Change Analysis

The goal of the ecological integrity and summary report is to give readers a snapshot of the condition status of a community at any given time. In addition to knowing status, managers also need to understand trends (i.e., is the measure indicating stability, decline, or increased health over time). To document trends over time, we will use repeat visits to the same plots to look at change over time and to develop reports that illustrate the overall trends for key measures over time. Although this process is not fully fleshed out, our team is working to fully develop our approach of change detection and document that approach in future iterations of this protocol.

Metrics Discussion

Tree Regeneration Metric/Deer Browse Metric

Overview: This metric assesses the quantity and composition of advance tree regeneration in the forest understory. Tree seedlings and saplings (> 5 centimeters [2 inches {in}] tall) are quantified by species and size class in eight 1.0 square meter (10.8 square feet [ft²]) nested subplots within the larger full plot. This metric should be used for forest sites only.

Metric Justification: Shade tolerant forest trees typically regenerate from seedling banks of advance regeneration present in the forest understory prior to disturbance. The quantity and species composition of advance regeneration will impact future canopy structure and composition. Regeneration can be affected by a variety of stressors, including air pollution, invasive exotic pressure, disturbance regime disruption, and climate change. Most notably, sustained, selective browsing by a historically high population of white-tailed deer is currently impacting seedling establishment, growth and composition in many parts the US (Gill 1992; Rooney 2001; Russell et al. 2001; Cote et al. 2004). Significant impacts on forest tree regeneration are associated with deer densities of greater than 8.5 per square kilometer (3.3 square miles [mi²]), well above presettlement

estimates of three to four deer per square kilometer for the northeast US and Eastern US in general. (Russell et al. 2001; Augustine and DeCalesta 2003).

Calculation and Scaling Rationale: Within CUPN forests, deer most likely selectively browse seedlings of preferred species that are at least 30 centimeters (11.8 in) and less than 75 centimeters (29.5 in) tall (Gill 1992; Kay 1993; Cornett et al. 2000). Sweetapple and Nugent (2004) developed a simple ratio of seedling diversity in browsed and unbrowsed size classes to assess ungulate impacts of forest understories. Adapting this approach for CUPN forest monitoring, a simple ratio of seedling species richness in heavily browsed size classes (50–137 centimeters [19.7–54 in] tall) versus shorter size classes (5–50 centimeters [2–19.7 in] tall) of preferred species will serve as an indicator of impacts on tree regeneration. Browse impacts on tree regeneration vary with species tolerance to browsing, and also with deer browse preference which varies seasonally and regionally. Potential deer browse impacts on tree species are estimated as High, Medium, and Low and are found on our comprehensive species list. Most species rated Medium are not preferred but can be heavily browsed when other choices are not available. Using only species with High to Medium deer impact ratings, the ratio is calculated as:

$$(\text{tall}-\text{short})/(\text{tall}+\text{short})$$

where *tall* and *short* are species richness, respectively, of tall (50–137 centimeters) and short seedlings (5–50 centimeters) of browsed species.

While this seedling ratio approach can be useful in detecting moderate impacts due to deer browsing, it will be less effective at detecting severe browsing impacts, which are likely to affect even seedlings less than 50 centimeters tall, as well as impacts on tree regeneration from other stressors, such as air pollution and climate change. An alternative approach by McWilliams et al. (2005) quantifies whether current seedling quantities are sufficient to restock a forest stand with canopy trees.

Their index, called the stocking index and developed for hardwood stands in Pennsylvania, awards and sums points for seedlings by size class within 2-meter (6.6 feet [ft]) radius circular microplot. Over the next two years, we will be developing a stocking index for stands in the Cumberland Piedmont Network based on stocking indices calculated in the region for high quality reference sites and low quality highly disturbed sites. Only seedlings of native species that typically form the high canopy in forested sites are counted (Table 3); this excludes shrub species such as *Vaccinium* spp. (blueberry species), *Amelanchier* sp. (serviceberry), *Cercis canadensis* (redbud), *Carpinus caroliniana* (American hornbeam), *Cornus florida* (flowering dogwood), and *Ostrya virginiana* (hornbeam), in addition to *Crataegus* sp. (hawthorns), *Hamamelis virginiana* (witchhazel), and exotic species such as *Lonicera* spp. (bush honeysuckles), and *Ligustrum sinense* (Chinese privet).

Good = Seedling ratio ≥ 0

Caution = Seedling ratio < 0

Significant Concern = Stocking index < 25

Confidence: Medium. Metric should be tested and fine-tuned. McWilliams et al. (2005) developed their stocking index for Pennsylvania hardwood stands subject to harvest, so it must be refined to apply to CUPN systems.

Table 3. Potential deer browse impact to tree species.

Species	Potential Deer Impact (Combination of Deer Preference and Plant Tolerance to Deer Herbivory)	Source ^{1,2,3}	Note
Cucumbertree (<i>Magnolia</i> spp.)	High	2	–
Eastern hemlock (<i>Tsuga canadensis</i>)	High	2	–
Flowering dogwood (<i>Cornus florida</i>)	High	1	–
Hackberry (<i>Celtis</i> spp.)	High	3	In Piedmont bottomlands
Red maple (<i>Acer rubrum</i>)	High	2	–
Sassafras (<i>Sassafras albidum</i>)	High	1	–
Sugar maple (<i>Acer saccharum</i>)	High	2	–
Tulip poplar (<i>Liriodendron tulipifera</i>)	High	2	–
Ashes (<i>Fraxinus</i> spp.)	Medium	2	High preference but medium browse tolerance
Black gum (<i>Nyssa sylvatica</i>)	Medium	3	In Piedmont bottomlands
Black walnut (<i>Juglans nigra</i>)	Medium	1	–
Elms (<i>Ulmus</i> spp.)	Medium	1	–
Hickories (<i>Carya</i> spp.)	Medium	2	High preference but medium browse tolerance
Oaks (<i>Quercus</i> spp.)	Medium	2	High preference but medium browse tolerance
Sycamore (<i>Platanus occidentalis</i>)	Medium	3	In Piedmont bottomlands
Witch hazel (<i>Hamamelis virginiana</i>)	Medium	1	–

Species	Potential Deer Impact (Combination of Deer Preference and Plant Tolerance to Deer Herbivory)	Source ^{1,2,3}	Note
Beech (<i>Fagus grandifolia</i>)	Medium/Low	2	Medium preference but high browse tolerance
White pine (<i>Pinus strobes</i>)	Medium/Low	1	Low choice but heavily browsed if needed
Black cherry (<i>Prunus serotina</i>)	Low	2	–
Black locust (<i>Robinia pseudoacacia</i>)	Low	1	–
Hop hornbeam (<i>Ostrya virginiana</i>)	Low	1	–
Ironwood (<i>Carpinus caroliniana</i>)	Low	1	–
Red cedar (<i>Juniperus virginiana</i>)	Low	1	–
Sweetgum (<i>Liquidambar styraciflua</i>)	Low	3	–

¹ NYS DEC. Winter Deer Foods. <https://www.dec.ny.gov/animals/7195.html>

² USFS 2003. Forest inventory and analysis. Northeast Field Guide, Version 1.7, App. 12.

³ Castleberry et al. 1999. Deer browse preferences in a southern bottomland hardwood forest. S. Jour. App. Forestry. 23 (2)

Tree Growth and Mortality Metric

Overview: Canopy tree growth and mortality rates provide an integrative, quantitative metric of tree health and vitality. Relative basal area growth rate (% basal area/year) of canopy trees is calculated from repeated measurements of bole diameter at breast height (DBH) measurements. Annual mortality rate (% stems/year) of canopy trees is also calculated from repeated observation.

Metric Justification: Tree growth rates can decline in response to environmental factors or anthropogenic stress, and tree mortality is often preceded by some years of reduced tree growth (Ward and Stephens 1997; Pedersen 1998; Dobbertin 2005). Tree basal area stem growth is affected by stress sooner than more critical growth of foliage or roots (Waring 1987) and is more straightforward to measure. Decreased growth or elevated mortality rate in trees of a particular species can indicate a particular health problem for that species, such as sugar maple decline (Hyink and Zedeker 1987; Duchesne et al. 2003); while altered vital rates for multiple species across a region may indicate regional environmental stress (Steinman 2004; Dobbertin 2005).

Calculation and Scaling Rationale: Typical growth and mortality rates vary by site, stand structural stage and by tree species, size and crown class (i.e., tree position in the canopy). For this reason, vital rates will be calculated by species and plot using only canopy trees (e.g., dominant, co-dominant or intermediate crown class) in stands that have succeeded to a mature or late-successional stage (see structural stage metric).

Relative basal area growth rate (% basal area/year) has been shown to be a useful predictor of tree mortality risk (Bigler and Bugmann 2003; Bigler et al. 2004). It will be calculated from successive DBH measurements as the percent change in basal area converted to an annual basis. For each live canopy tree, growth rate (*GR*; % basal area/year) is calculated as:

$$GR = ((BA_{t2} - BA_{t1}) * 100) / (BA_{t1} * \text{time})$$

where BA_{t2} and BA_{t1} are, respectively, basal area (m^2) for the present cycle and the previous cycle, and *Time* is the duration (years) between measurements. For each canopy tree, basal area (BA in m^2) is calculated from DBH (cm) as:

$$BA = \pi * (DBH / (2 * 100))^2$$

Growth rate is then averaged for canopy trees across the plot, and by species within the plot.

Choosing an appropriate reference for tree growth rate is complicated by variation in growth rate across regions, stand structural stages, species, and tree crown class. Steinman (2004) reported net growth rates for forests in the northeastern U.S. from USFS Forest Inventory and Analysis (FIA) data, using five categories: greater than 2, 2.0–1.6, 1.5–1.1, 1.0–0.6, and less than 0.6 %, with the first class considered good and the lower classes indicating cause for concern. As part of our ongoing work, CUPN staff will look at USFS FIA data for the Southeast to help interpret relative ecological integrity.

Annual mortality rate (*MR*; % stems/year) is calculated from successive observations as the percent of stems that died during an interval converted to an annual basis. This rate should be calculated for each plot, and for individual species within a plot as:

$$MR = (\text{Stems_died}_{t1-t2} * 100) / (\text{Stems_alive}_{t1} * \text{Time})$$

where $\text{Stems_died}_{t1-t2}$ is the number of stems that died during a measurement interval, and Stems_alive_{t1} is the number of stems that were alive during the measurement prior to the interval.

Typical annual tree mortality rates in old-growth forest range from 0.3% to 1.6% (Runkle 2000; Woods 2000; Busing 2005).

Good = Growth rate $\geq$ 60% of mean for region or species and Mortality rate $\leq$ 1.6 %; for plot and all individual species

Caution = Growth rate $<$ 60% of mean for region or species or Mortality rate $>$ 1.6%; for plot or any individual species

Tree Condition Metric

Overview: Qualitative observation of specific tree health problems and canopy foliage condition can provide an early warning indicator of problems or decline in canopy trees of a particular species or region. Some prominent exotic forest pests already established in or near CUPN parks include dogwood anthracnose (*Discula destructiva*), chestnut blight fungus (*Cryphonectria parasitica*), emerald ash borer (*Agrilus planipennis*) and hemlock woolly adelgid (*Adelges tsugae*). Other pathogens and insects such as sudden oak death (*Phytophthora ramorum*), laurel wilt (*Raffaella lauricola*) Asian longhorned beetle (*Anoplophora glabripennis*), and European gypsy moth (*Lymantria dispar*) may pose significant future threats to CUPN parks.

Metric Justification: Several exotic pests and pathogens are seriously impacting forest composition or structure in CUPN parks. The hemlock woolly adelgid (HWA) has caused widespread and rapid mortality of hemlock across the eastern U.S. since introduction here in the 1950s and threatens to rapidly and substantially reduce or eliminate eastern hemlock throughout much of its range, especially at Cumberland Gap National Historical Park (Orwig et al. 2002). Likewise, the emerald ash borer (EAB) is of high concern, as it has been documented at several CUPN parks since forest monitoring began. It quickly kills all native species of ash and will have dramatic impacts as it continues to spread into the southeastern United States (BenDor et al. 2006).

An exotic scale insect has caused the widespread occurrence of beech bark disease (BBD) throughout the Northeast. Caused by the interaction of this insect and a native fungus, beech bark disease has caused substantial mortality to American beech throughout the region, though most immature and some mature trees have some resistance to the disease. In areas of high beech mortality, increased sprouting of beech suckers can dramatically alter forest structure (Le Guerrier et al. 2003).

Butternut (*Juglans cinera*) is being killed throughout its range by an exotic fungus that causes butternut canker (BC; Furnier et al. 1999). Butternut is now far less common than it was even two decades ago because of the high mortality associated with this fungus.

Several other species pose grave threats if they advance into the region. The Asian longhorned beetle (ALB) poses an enormous threat to maple and other species if it invades rural and forested areas from its current documented occurrences in and near New York City and other East Coast and Midwest locales (Haack et al. 1997).

The fungal pathogen that causes sudden oak death (SOD) has been reported to be present on Long Island, N.Y., and could have dramatic impacts on oaks and other trees if it spread down the east coast (Venette and Cohen 2006).

If a forest pest or pathogen that is new to the park being monitored is detected, or suspected of occurring, a specimen of the pest, or a photo of the pest or symptoms should be made. These vouchers should be provided as quickly as possible to:

Clare Bledsoe, Biologist
Cumberland Piedmont Network
P.O. Box 8

Mammoth Cave, KY 42259

Clare_bledsoe@nps.gov

270-758-2132

This information can then be used to help with the early detection of forest pests.

This metric also assesses canopy foliage in canopy trees (e.g., dominant, co-dominant or intermediate crown class). As the season progresses, most trees will develop minor foliage problems (e.g., insect damage, chlorosis, etc.). However, more extensive damage to canopy foliage is indicative of tree health problems within a species or across a region.

Calculation and Scaling Rationale: Specific tree health problems and the condition of canopy foliage are qualitatively observed. For each tree, the amount of canopy foliage affected by various foliar problems (insect damage, chlorosis) is visually estimated within broad classes (0–10, 10–50, 50–90 and 90–100%). To assess ecological integrity specific health problems are tallied per plot, and foliage condition class is averaged across trees with a stand overall, as well as by species within the plot. Good condition is defined as minor foliage problems averaged across a stand and within individual species (represented by at least two individuals), and no evidence of damage by these specific invasive exotic pests and pathogens. More extensive foliage problems (10–50%) or evidence of damage by one of several invasive exotic pests and pathogens already widespread in the CUPN region (HWA, BWA, BBD, BC) indicate some cause for concern. Foliage damage above 50% averaged across a stand or within an individual species (represented by at least two individuals) indicates a more serious problem. Likewise, evidence that certain invasive exotic pests and pathogens of high concern for extensive mortality to trees (ALB, EAB, SOD) have reached CUPN forests indicates a significant concern which might still be controlled by management action.

Good = Average foliage problem $\leq 10\%$ and no HWA, BWA, BBD, BC, ALB, EAB or SOD

Caution = Average foliage problem 10–50 % for stand or species or evidence of HWA, BWA, BBD or BC

Significant concern = Average foliage problem $\geq 50\%$ for stand or species or evidence of ALB, EAB or SOD

Confidence: Medium. New exotic pests and pathogen threats to our forests arise with increasing frequency. This list of key health problems should be regularly reviewed and updated. The recognition of some specific forest health problems can readily be taught to seasonal staff (e.g., HWA, BBD). Other forest health problems will have a lower probability of detection by seasonal staff (e.g., ALB, EAB and SOD). Analysis must consider that foliage damage will typically increase as the field season progresses.

Snag abundance and Coarse Woody Debris Volume Metric

Overview: Dead wood, in the form of standing dead trees (snags) and fallen coarse woody debris (CWD) are important structural features of forest stands that provide habitat for wildlife and fungi.

This metric assesses the density of snags and volume of coarse woody debris in relationship to live tree density and volume.

Metric Justification: Snags and coarse woody debris provide important habitat for arthropods, herptiles, birds, small mammals and fungi. Snag retention is important for the federally endangered Indiana bat. Snags are particularly important for cavity-nesting birds, and the density and size of snags is indicative of habitat availability for those species (Dickson et al. 1983; Zarnowitz and Manuwal 1985; Schreiber and deCalesta 1992). Coarse woody debris is particularly important for herptiles and small mammals (DeGraaf and Rudis 1986; Petranka et al. 1994). Coarse woody debris continues to be used by wildlife as it breaks into smaller pieces over time, thus CWD volume can be a useful indicator of habitat availability. Large diameter snags persist longer than smaller diameter snags (Morrison and Raphael 1993; Garber 2005) and provide habitat for a greater number of vertebrate species (Conner et al. 1975; Cline et al. 1980; DeGraaf and Shigo 1985). Silviculture, land management and hazard tree removal can reduce the quantity or quality of these features; however, thoughtful land management can maintain or enhance snags and coarse woody debris (Keeton 2006).

Calculation and Scaling Rationale: Density of snags and volume of coarse woody debris in mature and late-successional stands varies substantially across ecosystems and with site conditions (Tyrrell et al. 1998). However, positive relationships between live and dead tree density and volume can be used to indicate expected snag and CWD levels (Sippola et al. 1998; Ferguson and Archibald 2002; Stewart et al. 2003).

For snags, Nilsson et al. (2003) have calculated a ratio of 1:9 standing dead:live trees for the boreal forest, while Ferguson found about 15% of standing trees were dead in the boreal forest. Goodburn and Lorimer (1998) report that 11% and 16% of standing trees were dead, respectively in Michigan and Wisconsin northern hardwood and hemlock northern hardwood stands. Since larger diameter snags tend to persist longer than smaller diameter snags (Garber 2005) and some studies report snag diameter distributions in late-successional stands which meet or exceed live tree diameter distributions (Goodburn and Lorimer 1998; Spetich et al. 1999; Nilsson et al. 2003), we can expect that these relationships should hold for large snags. Thus, we can suggest both overall (> 10 centimeter [3.9 in] DBH) and medium-large (≥ 30 centimeters [11.8 in] DBH) snag density should be at least 10% of overall and medium-large live tree density.

To develop a minimum snag density requirement, we reviewed recommendations based on land management and wildlife needs. Keddy and Drummond (1996) suggest at least four large (> 50 centimeters [19.7 in]) snags per 10 hectares (24.7 acres [ac]) for temperate deciduous forest. Other recommendations range from 0.35 to 2.5 large (> 45 centimeters [17.7 in]) snags per hectare to support wildlife (Tubbs et al. 1987). These recommendations suggest a minimum of at least five medium and large snags per hectare (2.5 ac).

To calculate snag density, the number of snags within a plot is summed, and converted to a per hectare basis as:

Snags/Plot_size

where *Snags* is the number of snags in a plot and *Plot_size* is the plot size in hectares (.04 for a 15-meter [49.2 ft] or 20-meter [65.6 ft] square plot).

For snags,

Good = At least 10% of all standing trees are snags and at least 10% of all medium-large (≥ 30 centimeters DBH) standing trees are snags

Caution = Less than 10% of standing trees are snags or large snags underrepresented relative to live trees

Significant concern = Fewer than five medium-large snags (≥ 30 centimeters DBH) per hectare

Huber's formula can be used to estimate CWD volume from line intersect transect data using the diameter of each CWD piece measured at the point of intersection with the transect line (Marshall et al. 2000). This formula can be simplified to calculate CWD volume per hectare (m^3/ha) as:

$$(\pi^2/(8*\text{Horiz_length}))*\sum \text{Diam}_i$$

where *Horiz_length* is the horizontal length of the transect in meters and *Diam_i* is the recorded diameter in centimeters of each piece of coarse woody debris. Please note that conversion factors for length (10,000) and areal units (also 10,000) have canceled out of this simplified equation and thus are not shown.

However, this calculation must be slope-corrected by converting the slope-length of each line intersect transect (15 meters [49.2 ft]) to its equivalent horizontal distance (Van Wagner 1982). Inserting a correction factor into the formula above allows calculation of CWD volume per hectare (m^3/ha) as:

$$\text{CWD} = \pi^2 (\text{Sqrt}(1+(\%Slope/100)^2)/(8*Slope_length))*\sum \text{Diam}_i$$

where *%Slope* is slope percent of the transect rounded to the nearest 5%, and *Slope_length* is the slope length of the transect in meters (i.e., 15 meters).

This calculation must be made for each of the two transects in a plot. Then, CWD volume per hectare at each plot is calculated as the average from both transects in a plot.

For comparison and rating, a simple, conservative estimate of live tree (stem and branches ≥ 10 centimeters DBH) volume will be made from individual tree measurements and stand height using the geometric formula for a paraboloid. This calculation is conservative because volume from both stem and branches (≥ 10 centimeters diameter) should exceed paraboloid volume; this will provide additional confidence that ratings of caution or significant concern are warranted. While more nuanced equations exist for calculating stem volume from DBH and height measurements for different species, those equations do not include volume of large branches. Thus, those more complex calculations are unlikely improve accuracy in this case.

Tree volume (*v* in m^3) is calculated for each live tree in the plot as:

$$v = (DBH * h_c) / 400$$

where DBH is the diameter at breast height of the tree (centimeters), and h_n is an estimate of tree height (meters) from stand height adjusted for tree canopy position. For codominant trees, h_c is equivalent to measured stand height. For dominant trees, intermediate and sub-canopy trees, respectively, h_c will be estimated as 1.1, 0.8 and 0.5 stand height, respectively.

Volume of all live trees in the stand is then summed and converted to a per hectare basis to yield an estimate of stand volume (V in m^3/ha):

$$V = \sum v_i / \text{plot_size}$$

where plot_size is the plot size in hectares (0.04 for a 20-m square plot).

Volume of dead wood in boreal stands has been reported to range from about 20-40% of total (live and dead) wood volume (Linder et al. 1997, Kuuluvainen et al. 1998, Siitonen et al. 2000, Sippola et al. 1998, Karjalainen and Kuuluvainen 2002), of which about 70% is downed coarse woody debris (Siitonen et al. 2000, Sippola et al. 1998). Stewart et al. (2003) found dead wood to be 20-28% of live tree volume in late-successional hemlock-spruce-pine and northern hardwood stands, of which about 70% was downed coarse woody debris.

For CWD

Good = CWD volume $\geq$ 15% of live tree volume

Caution = CWD volume < 15% of live tree volume

Confidence: Medium. Since CUPN plots are not designed to pick up rare features such as snags, snag abundance should be evaluated at the scale of the park only. Some forested systems within CUPN parks are relatively young and will likely fall short of late-successional coarse woody debris and snag benchmarks for some time.

Biotic Homogenization and/or Floristic Quality Metric

Overview: Biotic homogenization is the process by which regional biodiversity declines over time due to the addition of widespread exotic species as well as the loss of native species (Olden and Rooney 2006). This metric assesses homogenization of forest and woodland biotas by calculating trend over time in Jaccard's similarity index.

Metric Justification: Recognition of the extent, magnitude and implications of biotic homogenization due to human activities is growing (Lockwood and McKinney 2001; Olden 2006). Homogenization occurs when regional floras become more similar due to the addition of wide-spread exotic species as well as the extirpation of endemic species. While this process has occurred in the geologic past, most notably when previously separate land masses have become contiguous, activities of modern humans have dramatically increased the rate of biotic homogenization (McKinney and Lockwood 1999). This process is driven both by the spread of invasive exotic species associated with human activity, as well as by physical and environmental habitat modification by humans including land use and

climatic change. Tracking the extent and magnitude of biotic homogenization over time provides a useful metric indicative of the effect anthropogenic change is having upon regional biological diversity.

Floristic quality has been used in the Midwest, Northeast, and Southeastern states to capture decreases and increases in “quality” of vascular plant flora. It attempts to quantify “conservativeness” of the flora of a plot or sample area and can be used to monitor areas to see changes over time.

Calculation and Scaling Rationale: The Cumberland Piedmont Network will calculate an average Jaccard's similarity index of the total species composition for each plot, as compared to every other plot within the park (Olden and Poff 2003). For any two sites, Jaccard's index is defined as the ratio between species present at both sites (intersection) divided by the total species present at either site (union). The index (J) will be calculated as:

$$J(X_o) = (\sum_{i=1}^n (\cap X_i) / (X_o \cup X_i)) / n$$

where X_o is the plot in question, x_i represents another plot within the park, and n is the total number of plots at the park. Jaccard's index ranges from 0 (representing no species in common) to 1 (all species in common). Trend will be determined by comparing Jaccard's index between successive measurements.

Good = No increasing trend of homogeneity, average coefficient of $C > 3$

Caution = Trend of increasing homogeneity, average coefficient of C between 1.5 and 3

Significant Concern = Average coefficient of C less than 1.5

Confidence: Medium. Metric should be assessed for sensitivity and fine-tuned when trend data area available.

Indicator Species—Invasive Exotic Plants Metric

Overview: This metric assesses the presence of key invasive exotic plant species within CUPN exotic plant species within forested, woodland and successional ecosystems.

Metric Justification: The effects of invasive exotic species on the structure, composition and function of natural systems have become a chief concern of ecologists and land managers of the last 20 years due to the growing number of species successfully exploiting and altering native habitats (Drake et al. 1989)

Calculation and Scaling Rationale: The average number of key invasive exotic plant species is summed by plot, then averaged across the park. Indicator species were selected based on their potential threats (Miller et al. 2010) and presence data within the CUPN units (extracted from the NPSpecies database).

Good = No key invasive exotic species present in plot

Caution = 1 to 3 invasive exotic species present in plot or at least 10% relative cover of invasive exotic species compared with total cover of all species in plot

Sig Concern = 4 or more key invasive exotic species present per plot or 25% relative cover of invasive exotic species compared with total cover of all species in plot

Table 4. High priority invasive exotic plant species of Cumberland Piedmont Network (first draft).

Scientific Name	Common Name	Habitat
<i>Ailanthus altissima</i>	Tree-of-heaven	Edges, rock outcrops, forest gaps
<i>Albizia julibrissin</i>	Mimosa	Edges and forest interiors
<i>Alliaria petiolata</i>	Garlic mustard	Forest and open habitats
<i>Celastrus orbiculatus</i>	Oriental bittersweet	Edges and forest interiors
<i>Centaurea biebersteinii</i>	Spotted knapweed	Open habitats, meadows
<i>Cirsium vulgare</i>	Bull thistle	Open habitats, meadows
<i>Clematis terniflora</i>	Autumn clematis	Wetland and upland forests, edges
<i>Elaeagnus pungens</i>	Thorny elaeagnus	Disturbed forests
<i>Elaeagnus umbellata</i>	Autumn olive	Disturbed forests
<i>Euonymus alata</i>	Burning bush	Forest and successional habitats
<i>Euonymus fortunei</i>	Climbing euonymus	Forest and successional habitats
<i>Ligustrum sinense</i>	Chinese privet	Wetland and upland forests, edges
<i>Lonicera fragrantissima</i>	Breath-of-spring	Open and forest habitats
<i>Lonicera japonica</i>	Japanese honeysuckle	Forest and successional habitats
<i>Lonicera maackii</i>	Amur honeysuckle	Forest and successional habitats
<i>Microstegium vimineum</i>	Japanese stiltgrass	Open and forest habitats
<i>Miscanthus sinensis</i>	Chinese silvergrass	Open and forest habitats
<i>Nandina domestica</i>	Nandina	Open and forest habitats
<i>Paulownia tomentosa</i>	Princess tree	Open and successional habitats, disturbed forests
<i>Sorghum halepense</i>	Johnson grass	Open and successional habitats
<i>Spiraea japonica</i>	Japanese meadowsweet	Open and forest habitats
<i>Rosa multiflora</i>	Multiflora rose	Open and successional habitats
<i>Wisteria floribunda</i>	Japanese wisteria	Open and successional habitats
<i>Wisteria sinensis</i>	Chinese wisteria	Open and successional habitats

Confidence: Medium. The list of key invasive exotic species should be reviewed and updated periodically by CUPN staff and park natural resource managers.

Stand Structural Stage Metric

Overview: This metric assesses the structural stage distribution of forest stands in relation to the expected distribution under natural disturbance regimes. It provides an indicator of altered disturbance regimes, and habitat availability for species dependent on specific structural stages. Stand structural stage is assessed from tree size and canopy position measurements.

Metric Justification: At landscape scales, the distribution of stand structural stage affects the maintenance of biological diversity, particularly of species dependent upon specific structural stages. As multiple stressors including global change and exotic pest and pathogen outbreaks alter disturbance regimes (Dale et al. 2001), structural stage distributions are likely to shift.

Calculation and Scaling rationale: Stand structural class is calculated for each plot from tree size and canopy position measurements using a method like Frelich and Lorimer (1991) but substituting basal area for exposed crown area (Goodell 2004). Stands are classified as pole, mature, late-successional stage or mosaic based on relative basal area of live canopy trees within pole (10–25.9 centimeters [3.9–10.2 in] DBH), mature (26–45.9 centimeters [10.2–18.1 in] DBH) and large size (≥ 46 centimeters [18.1 in] DBH) classes. This calculation uses only canopy trees as defined by tree crown class (dominant, sub-dominant or intermediate but not sub-canopy). Trees within the open-grown crown class are also excluded to avoid misinterpreting early-successional stands dominated by a few, large open-grown trees as late-successional.

To calculate this metric, begin by calculating basal area (BA in square meters [m^2]) for each live canopy tree in a plot from DBH (diameter at breast height in centimeters):

$$BA = \pi * \left(\frac{DBH}{2 * 100}\right)^2$$

Next, relative basal area per size class is calculated for the stand by summing the BA of canopy trees within each DBH size class (pole, mature and large as defined above), and then dividing by the total basal area of the plot.

Finally, stand structural stage is assigned to the plot based on the relative basal area distribution as follows:

Pole stage: $\geq 67\%$ BA in pole plus mature sizes, with more basal area in pole than mature size

Mature stage: $\geq 67\%$ BA in pole plus mature sizes, with more basal area in mature than pole size or $\geq 67\%$ in mature plus large size, with more basal area in mature than large size

Late-successional stage: $\geq 67\%$ BA in mature plus large sizes, with more basal area in large than mature size

Mosaic: Any stand not meeting the above criteria

For oak-hickory forests, Lorimer and White (2003) suggest that multi-cohort stands may have occupied 25–40% of the landscape. Park rating is interpreted from ratings of dominant ecosystems at each park.

Good = At least 25% late-successional stand structure, respectively in oak-hickory dominated forests

Caution = Less than 25% late-successional stand structure in oak-hickory dominated forests

Confidence: Medium. Metric can be fine-tuned over time as more data becomes available.

Soil Chemistry—Acid Stress Metric (optional)

Overview: The molar ratio of calcium to aluminum (Ca:Al) in soil or soil solution has been developed as an indicator of acidification stress to forest vegetation (Cronan and Grigal 1995)

Metric Justification: Acidic deposition acidifies soil, leaching important base cations (e.g., Ca^{2+} , Mg^{2+} , K^{+}) from the soil and increasing availability of aluminum; this deprives vegetation of necessary nutrients, and increases availability of a toxin (Al_i). Broad-scale patterns of wet deposition across the east are well characterized (Driscoll et al. 2001). However, substantial additional acidity can result from dry and occult deposition, and these patterns of deposition are not well characterized.

Calculation and Scaling Rationale: Ca:Al ratio is calculated as the molar ratio of NH_4Cl -extractable ions (Ca^{2+} and inorganic charged Al). Ca and Al data are typically reported as mg/kg of sample or mg/L of extractant; data reported thus will need to be converted to molar concentrations by dividing each concentration by the molar mass of the element in question (40.08 g/mol for Ca; 26.98 g/mol for Al). The Ca:Al ratio is then calculated as the simple ratio of the molar concentrations.

Cronan and Grigal (1995) critically reviewed the literature to determine the utility of Ca:Al ratio in soil solution as an ecological indicator of acid stress to vegetation. Based on this review, they estimated a 50% risk of adverse impacts on growth or nutrition across a wide range of tree species when the soil solution Ca:Al ratio is as low as 1.0. However, sensitivity to acid stress varies among species, and Cronan and Grigal (1995) note impacts have been reported at higher Ca:Al ratios for red oak (4–5), sugar maple (2.5), and several conifers (>1); Decker and Boerner (1997) reported a Ca:Al ratio of 4.0 depressed growth, production and nutrient uptake in tulip poplar. Driscoll et al. (2001) suggest that Ca:Al ratio can recover over time if acid deposition levels are reduced, and Ca:Al ratio can be used to judge ecosystem recovery.

For practicality, we will assess exchangeable Ca:Al from soil samples rather than directly sampling soil water. The former is related but not identical to the latter (David and Lawrence 1996) and soil exchangeable Ca:Al ratio been used as a surrogate indicator (Lyon and Sharpe 1999; Wargo et al. 2002). Calcium and aluminum vary substantially through the soil profile (Yanai et al. 2005). Vegetation will be most affected by the Ca:Al ratio of soil in contact with fine roots, the bulk of which are found in the O and A horizons (or in the upper soil depth if not separated by horizon).

Good = Ca:Al ratio ≥ 4.0 in O and A horizons or in upper depth

Caution = Ca:Al ratio from 1 - 4 in O or A horizon or in upper depth

Significant concern = Ca:Al ratio ≤ 1.0 in O or A horizon or in upper depth

Confidence: Medium. Spatial and temporal variation in soil properties is typically quite high and may impede detection of significant trends. Yanai et al. (2005) have shown that small differences in separation of soil layers between years are likely to impact Ca:Al ratios.

Soil Structure and Layers Metric (optional)

To be developed at some future date.

Landscape Connectivity and Anthropogenic Land Use Metric

Overview: This metric assesses the percentage of land in anthropogenic versus natural land use in the local neighborhood (50 hectares [123.6 ac]) of each forested plot.

Metric Justification: Habitat loss and fragmentation have synergistic, cumulative impacts upon remaining natural areas. As more habitat is lost, the remaining fragments become more important to remaining wildlife populations and are also more likely to be isolated and impacted by surrounding anthropogenic land use. The Heinz Center (2002) calculated similar neighborhood statistics on immediate (2 hectares [4.9 ac]), local (65 hectares [160.6 ac]) and larger neighborhoods (5,000 hectares [12,355 ac]). We will at least plan on assessing at the 50 hectare and 100 hectare (247.1 ac] scales.

Calculation and Scaling Rationale: Calculation of the percentage of land within the local neighborhood (a 400 meter [1,312.3 ft] circle from plot center) in anthropogenic versus natural land use is made using a combination of the vegetation maps and [National Land Cover Database](https://www.usgs.gov/centers/eros/science/national-land-cover-database) (<https://www.usgs.gov/centers/eros/science/national-land-cover-database>). Plantations of native species will be considered natural land use, while plantations of primarily exotic species will be considered anthropogenic land use.

Percolation theory offers a framework for assessing the combined impacts of habitat loss and fragmentation (O'Neill et al. 1997). Simulations show a marked increase in the likelihood of continuous habitat corridors existing in a landscape that has more than 60% natural cover (Gardner et al. 1992).

Good = 10% or less anthropogenic land use

Caution = 10–40% anthropogenic land use

Significant concern = 40% or more anthropogenic land use

Confidence: Medium. This metric may be more relevant at the scale of the park, while forest patch size (above) may provide more useful information at the scale of the plot. It is not clear whether fields that are kept open by mowing but not cropped (and provide habitat for grassland birds) should be considered natural or anthropogenic land use.

Patch Size Metric

Overview: Forested areas throughout the Southeast within a matrix of managed, rural, and suburban habitat that limit the ability of species to freely forage, interbreed and disperse, and create "edge" habitats which differ from forest interior in environmental conditions, structure and composition and disturbance.

Metric Justification: A large and growing body of scientific literature documents the negative impacts of habitat fragmentation on biodiversity in a wide variety of ecological systems (Fahrig 2003). The impacts of fragmentation have been especially well documented upon avian communities, and population declines of a variety of forest interior avian species are linked to habitat fragmentation (Rich et al. 1994; Austen et al. 2001; Boulinier et al. 2001). In general, large forest patches tend to support larger populations of fauna and more native, specialist, and forest interior species (Harris 1984; Forman 1995).

Calculation and Scaling Rationale: Contiguous forested patch size surrounding each plot is calculated in hectares using GIS.

Kennedy et al. (2003) reviewed the literature on minimum patch area for a variety of taxa and found minimum patch areas ranged up to 1 hectare (2.5 ac) for invertebrates, up to 10 hectares (24.7 ac) for small mammals, up to 50 hectares (123.6 ac) for the majority (75%) of birds species, and up to over 200,000 hectares (494,211 ac) for large mammals. Since few large mammals are documented to exist in the relatively small parks of this network, ratings herein are based on the needs of birds, small mammals and invertebrates.

Good = At least 50 hectares

Caution = Less than 50 hectares

Significant concern = Less than 1 hectare

Confidence: Medium. While patch size and fragmentation impacts on particular species have been well documented, developing an overall rating for an ecosystem or group of ecosystems is more complex, and may be refined over time.

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Revision Log

Revision History Log.

Version #	Date	Revised by	Changes
1.1	8/28/2023	C. Bledsoe	Minor format changes, such as moving revision history to end of SOP, to match format of other protocol SOPs. NO CHANGES OR UPDATES MADE TO ORIGINAL (2011) TEXT. Formatted by editor to regional I&M publication standards