Monitoring and evaluating the ecological integrity of forest ecosystems

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"Ecological integrity" provides a useful framework for ecologically based monitoring and can provide valuable information for assessing ecosystem condition and management effectiveness. Building on the related concepts of biological integrity and ecological health, ecological integrity is a measure of the composition, structure, and function of an ecosystem in relation to the system's natural or historical range of variation, as well as perturbations caused by natural or anthropogenic agents of change. We have developed a protocol to evaluate the ecological integrity of temperate zone, forested ecosystems, based on long-term monitoring data. To do so, we identified metrics of status and trend in structure, composition, and function of forests impacted by multiple agents of change. We used data, models, and the scientific literature to interpret and report integrity using "stoplight" symbology, ie "Good" (green), "Caution" (yellow), or "Significant Concern" (red). Preliminary data indicate that forested ecosystems in Acadia National Park have retained ecological integrity across a variety of metrics, but that some aspects of soil chemistry and stand structure indicate potential problems. This protocol was developed for the National Park Service Vital Signs Monitoring Program and holds promise for application in the temperate zone, forested ecosystems of eastern North America.

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As managers, scientists, and policy makers increasingly recognize the value of ecological monitoring (Lovett *et al.* 2007), new monitoring programs are being implemented, and existing programs are undergoing redesign and improvement (Busch and Trexler 2003). Current investment in careful planning and design of monitoring programs will result in high-quality data for years to come. How can scientists and natural resource managers identify the most useful data to collect, and how can they effectively convey critical information – describing ecosystem condition – to policy makers and the public?

Common challenges encountered in developing a monitoring program include identifying specific monitoring objectives, deciding what data to collect, and effectively interpreting and communicating the results (Noon 2003). Monitoring objectives are driven by management goals and will vary considerably among programs. For example, specific objectives for monitoring a forest managed for timber production may focus on tree regeneration and productivity, whereas those for monitoring a forest preserve may focus instead on maintenance of "natural" condition or preservation of wildlife habitat. Once objectives have been established, careful consideration should be given to the selection of specific variables to accomplish those objectives. Because it is impossible to monitor all the variables of interest, some criteria or process must be used to identify those that will provide the most useful information relative to the cost of measurement. Finally, a monitoring program will only fulfill its function if results are interpreted and reported in a way that is meaningful to a broad audience. Scientific reporting is important, but may reach only a fraction of those that need the information.

The concept of "ecological integrity" provides a useful framework for selecting monitoring variables and assessing progress toward ecologically based management goals (Harwell *et al.* 1999). As part of the National Park Service's (NPS) Vital Signs Monitoring Program (http://science.nature.nps.gov/im/monitor/), we developed a protocol for monitoring the ecological integrity of temperate zone, forested ecosystems of the northeastern US. This protocol was developed specifically for the small, forested parks that make up the NPS Northeast Temperate Network (NETN), including Acadia National Park and a group of smaller (30- to 1400-ha) national historical parks and sites

In a nutshell:

- "Ecological integrity" measures the composition, structure, and function of an ecosystem, as compared with its natural or historical range of variation
- This approach acts as a yardstick for evaluating impacts caused by natural or man-made agents of change, as well as providing feedback on the effectiveness of management strategies
- We report on forest integrity using intuitive "stoplight" symbology, ie "Good" (green), "Caution" (yellow), or "Significant Concern" (red)

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(NHPs; Figure 1). Forest ecosystems within these parks have been (or are in the process of being) inventoried (Table 1). NHPs are protected from development, but are managed for historical and cultural uses, which may include agriculture and silviculture. More information describing these parks can be found on the NETN website (http://science.nature.nps.gov/im/units/netn/).

Our protocol provides specific instructions for establishing and monitoring permanent forested plots for a variety of structural, compositional, and functional metrics, from which we evaluate ecological integrity. Herein, we summarize our protocol, its application, and a preliminary assessment for Acadia National Park, a 19 000-ha park on the coast of Maine.

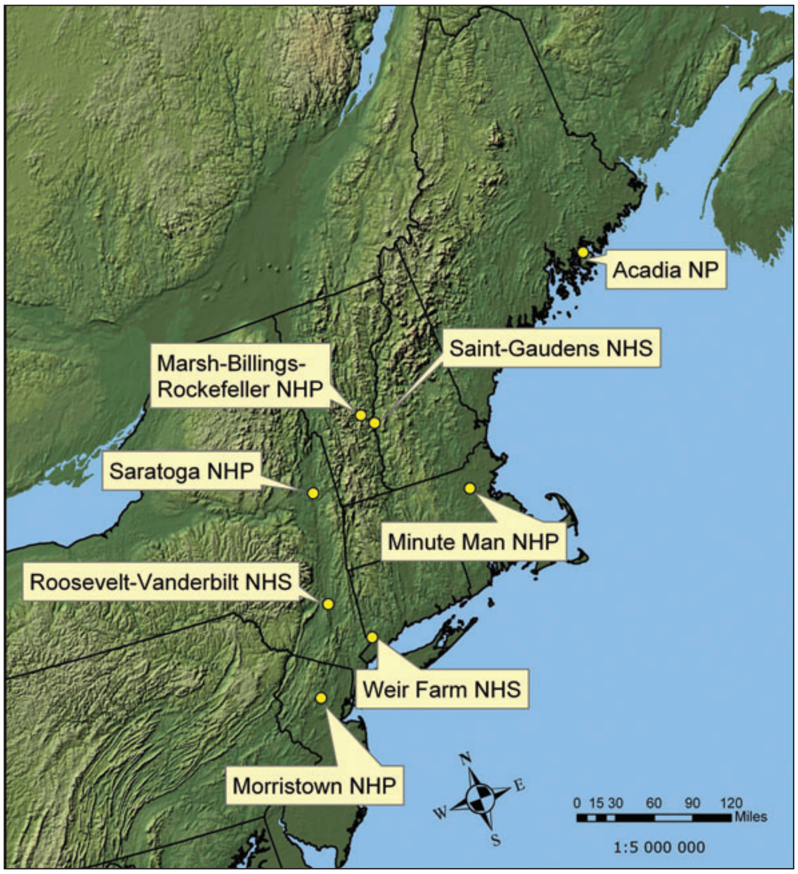

Figure 1. *Map of US National Park Service's Northeast Temperate Network parks monitored for forest integrity. NHP = National Historic Park; NHS = National Historic Site; NP = National Park.*

What is ecological integrity?

Building on the related concepts of biological integrity and ecological health, ecological integrity is a broad and useful endpoint for ecological assessment and reporting (Czech 2004). "Integrity" is defined as the quality of being unimpaired, sound, or complete. To have integrity, an ecosystem should be relatively unimpaired across a range of characteristics, and across spatial and temporal scales (De Leo and Levin 1997). Ecological integrity has been defined as a measure of the composition, structure, and function of an ecosystem in relation to the system's natural or historical range of variation, as well as perturbations caused by natural or anthropogenic agents of change (Parrish *et al.* 2003).

The utility of ecological integrity as a yardstick in forest preserves is clear. When the primary goal for land management is preservation of forest ecosystems, assessment of deviation from a system's natural or historic range of variation in composition, structure, or function is a clear measure of success or failure. Is the concept of ecological integrity also useful for assessing lands managed for cultural resources or other values, such as timber production? It is more challenging to apply ecological integrity in situations where management goals may conflict with some elements of ecological integrity. Yet, in cases where preservation is also a primary or secondary management goal, assessment of ecological integrity can improve understanding of the impacts of particular management techniques or specific objectives, as well as the impacts of key stressors, such as air pollution or climate change. For example, NHPs are managed for cultural goals, such as the preservation of historic landscapes, in addition to conservation of natural resources. Several of the NHPs in the eastern US contain historic battlefields that replace and fragment forests that would otherwise occupy these sites. Consideration of ecological integrity can help managers to choose landscape configurations that balance natural and cultural goals, as well as to understand the impacts of important regional stressors such as air pollution.

Ecological integrity is not easy to assess. One promising approach builds upon the well-known Index of Biological Integrity (IBI). The original IBI interpreted stream integrity based on 12 metrics that reflected the health, reproduction, composition, and abundance of fish species (Karr 1981). Each metric was rated by comparing measured values with the values expected under relatively unimpaired conditions, and the ratings were aggregated into a total score. Related biotic indices have sought to assess the integrity of other aquatic and wetland ecosystems, primarily via faunal assemblages. Building upon this foundation, others have suggested measuring the integrity of ecosystems by developing suites of indicators or metrics comprising the key biological, physical, and functional attributes of those ecosystems (Andreasen *et al.* 2001; Parrish *et al.* 2003).

A first step in determining ecological integrity is identifying a limited number of metrics that best distinguish a highly impacted, degraded, or depauperate state from a relatively unimpaired, complete, and functioning state. Metrics may be properties that typify a particular ecosystem or attributes that change predictably in response to

Table 1. Forest area (ha) by ecological system within eight NETN parks

NatureServe ecological system	*ACAD*	*SARA*	*MORR*	*MABI*	*MIMA*	*ROVA*	*SAGA*	*WEFA*
Acadian lowland spruce-fir–hardwood forest	6786							
Boreal aspen–birch forest	1166							
Laurentian–Acadian northern hardwoods forest	312	273		33	20	83	13	1
Laurentian–Acadian pine–hemlock–hardwood forest	923			97		77	19	
Appalachian hemlock–hardwood forest		432						
Central and southern Appalachian northern hardwood forest			44					
Central Appalachian oak and pine forest			229	1				20
Northeastern interior dry oak forest						112	3	
Laurentian–Acadian white pine–red pine forest	731							
Plantation – native species		4		45		2	11	
Plantation – exotic species				18		12		
Old-field successional habitat		162	193	3	62	15		

Notes: ACAD = Acadia National Park in coastal ME; SARA = Saratoga National Historical Park (NHP) in Stillwater, NY; MORR = Morristown NHP in Morristown, NJ; MABI = Marsh-Billings-Rockefeller NHP in Woodstock, VT; MIMA = Minute Man NHP in Concord, MA; ROVA = the Roosevelt-Vanderbilt National Historic Sites (NHS), headquartered in Hyde Park, NY; SAGA = Saint-Gaudens NHS in Cornish, NH; WEFA = Weir Farm NHS in Wilton, CT. ROVA column does not include recent acquisition.

anthropogenic stress. The suite of metrics selected should be comprehensive enough to incorporate composition, structure, and function of an ecosystem across a range of spatial scales. Ideally, indicators of the magnitude of key stressors acting upon the system will be included to increase understanding of the relationships between stressors and effects.

A conceptual ecological model – delineating linkages between key ecosystem attributes and known stressors or agents of change – is a useful tool for identifying and interpreting metrics with high ecological and management relevance (Noon 2003). We developed a simple conceptual model that identifies (a) important drivers and stressors acting upon forest ecosystems of the northeastern US, and (b) useful measures of forest structure, composition, and function impacted by those stressors (Figure 2). A more detailed description of how these stressors affect structural, compositional, and functional metrics is included within the NETN Vital Signs Monitoring Plan (Mitchell *et al.* 2006). In addition to having ecological and management relevance, useful metrics should discriminate long-term trends from temporal and spatial variability, as well as from measurement error, and be both feasible and cost-effective to implement. Justification for the selection of each metric is critical and is provided below.

A second step in determining ecological integrity is establishing assessment points that distinguish expected or acceptable conditions from undesired ones that warrant concern, further evaluation, or management action (Bennetts *et al.* 2007). Assessment points for rating ecological integrity are based upon natural or historic variability. Estimates of historical or natural variation in ecosystem attributes provide a reference for gauging the effects of current anthropogenic stressors, while at the same time recognize the inherent natural variation in ecosystems across space, time, and stages of ecological succession (Landres *et al.* 1999).

Current knowledge of historic or natural conditions is based on historical studies and records, paleoecological reconstructions of past conditions, current studies of relatively pristine ecosystems, and efforts to model ecosystem dynamics. Although all of these 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 extrapolating these data to other areas. Ratings therefore need to be reviewed and updated as our knowledge of the historic or natural variations and the ecosystem response to perturbation increases over time.

We use three categories to interpret ecological integrity for a broad audience, reported using "stoplight" symbology: "Good" (green), "Caution" (yellow), and "Significant Concern" (red). "Good" represents an acceptable or expected condition, "Caution" indicates that a problem may exist, and "Significant Concern" signifies undesirable conditions that may require management correction. For several metrics, we have not defined conditions that merit "Significant Concern" because current knowledge is insufficient to justify this rating.

What does forest integrity look like?

We evaluate ecological integrity of forested systems using 13 metrics (Table 2). We developed metrics and ratings that are broadly applicable across northeastern temperate forests, but in one case supply ratings for more specific ecosystem types. Each metric is briefly described below. The full protocol (Tierney *et al.* in review) – including field methods, sampling design, and calculations – is available on the NETN website, and will continue to be updated and revised over time.

Our protocol includes two measures of landscape structure: forest patch size and anthropogenic land use. Forested areas in the northeastern US occur within a matrix of managed, rural, and suburban habitats that limit the ability of species to forage, interbreed, and disperse, and also creates "edge" habitats that differ from forest interiors in many ways. Patterns of fragmentation determine *forest patch size*, which strongly impacts habitat suitability for a variety of taxa (Fahrig 2003). Large forest patches tend to support larger populations of fauna and more native, specialist, and forest interior-dwelling species. Kennedy *et al.* (2003) reviewed minimum patch size needed by several taxa and found that minimum patch areas ranged up to 1 ha for invertebrates, up to 10 ha for small mammals, and up to 50 ha for the majority (75%) of bird species. The relatively small parks for which this protocol was designed cannot independently support large mammal populations, so our ratings are based on the needs of birds, small mammals, and invertebrates. In other areas, it will be necessary to consider the needs of large mammals, which require substantially larger forest patches.

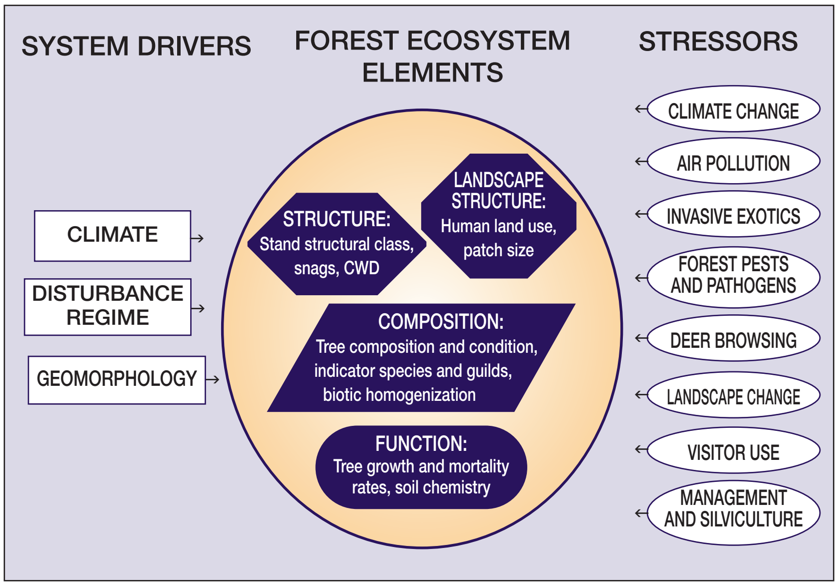

Figure 2. *Conceptual ecological model showing key drivers and stressors influencing elements of structure, composition, and function in forests of the northeast US. CWD = coarse woody debris.*

Habitat loss and fragmentation have cumulative impacts upon remaining natural areas. As more habitat is converted to *anthropogenic land use*, the remaining fragments become more important to existing wildlife populations, and are also more likely to be isolated and impacted by surrounding land use. Theoretical models offer a framework for assessing the combined impacts of habitat loss and fragmentation. Simulations show a marked increase in the likelihood of continuous habitat existing in a landscape that has more than 60% natural cover (O'Neill *et al.* 1997; McIntyre and Hobbs 1999). We calculate the percentage of land area devoted to human versus "natural" land use within a 50-ha circle surrounding each forest plot, in order to estimate the impacts of habitat loss within a local neighborhood (Heinz Center 2002).

We include three measures of forest structure: stand structural class, snag abundance, and coarse woody debris (CWD) volume. Forested stands recovering from recent disturbance differ structurally from later successional stands. The distribution of stand structural stage is important for maintaining a full complement of native species, which vary in their dependence upon different successional stages. Human alteration and management have greatly changed the structural stage distributions of eastern forests, and these distributions will be further affected by altered disturbance regimes coincident with global change and exotic pest and pathogen outbreaks (Dale *et al.* 2001). Comparison of existing distributions with those expected under natural disturbance regimes provides an indicator of altered disturbance regimes as well as habitat availability. We calculate stand structural stage from tree size and canopy position measurements, using a method similar to that of Frelich and Lorimer (1991), but substituting basal area for exposed crown area (Goodell and Faber-Langendoen 2007). We assign ratings based on expected percentage of late-successional forest stages across the landscape as compiled by Frelich and Lorimer (1991) and Lorimer and White (2003).

Dead wood, in the form of *snags* (standing dead trees) and fallen *CWD*, is an important structural component that provides necessary habitat for many forest taxa. Snags are particularly important for cavity-nesting birds, whereas CWD is used by invertebrates, herptiles, and small mammals. Silviculture and land management often reduce the quantity and quality of dead wood; however, ecologically based land management can retain these features (Keeton 2006). We use the relationships between live and dead wood to interpret snag abundance (Goodburn and Lorimer 1998; Nillson *et al.* 2003) and CWD volume (Siitonen *et al.* 2000; Stewart *et al.* 2003). A minimum snag density of at least five medium-to-large snags (≥30 cm diameter-at-breast-height, or dbh) per hectare is inferred, based on wildlife needs (Tubbs *et al.* 1987).

■ Metrics of forest composition

We use five metrics to interpret forest composition. *Tree regeneration* indicates the quantity and composition of established tree seedlings and therefore of future canopy composition. Selective browsing by a historically large population of white-tailed deer (*Odocoileus virginianus*) is a key stressor, substantially impacting seedling establishment in several parts of the eastern US (Cote *et al.* 2004). To interpret ecological integrity from regeneration data, we take two approaches. Deer preferentially browse particular seedling species and size classes (30–75 cm tall; Cornett *et al.* 2000). To assess deer impacts, Sweetapple and Nugent (2004) developed a simple ratio of seedling species richness in browsed versus unbrowsed size classes of preferred species. We use this ratio to distinguish "Good" from "Caution". A complementary approach by

Table 2. Metrics and ratings for evaluating the ecological integrity of forest ecosystems

		Rating		
Metric type	*Metric*	*Good*	*Caution*	*Significant Concern*
Landscape structure	Forest patch size	>50 ha	10–50 ha	< 10 ha
	Anthropogenic land use	<10%	10–40%	> 40%
Structure	Stand structural class	≥ 70% of stands are late-successional	< 70% of stands are late-successional in northern hardwood, hemlock–hardwood, or upland spruce–hardwood forest	
		≥ 30% of stands are late-successional	< 30% of stands are late-successional in lowland spruce–hardwood forest	
		≥ 25% of stands are late-successional	< 25% of stands are late-successional for other forest systems	
	Snag abundance	≥10% of standing trees are snags and ≥ 10% of med–lg trees are snags	< 10% of standing trees are snags or < 10% of med–lg trees are snags	< 5 med–lg snags/ha
	Coarse woody debris volume	>15% live tree volume	5–15% live tree volume	< 5% live tree volume
Composition	Tree regeneration	Seedling ratio ≥ 0	Seedling ratio < 0	Stocking index outside acceptable range
	Tree condition	Foliage problem <10% and no priority 1 or 2 pests	Foliage problem 10–50% or priority 2 pest	Foliage problem >50% or priority 1 pest
	Biotic homogenization	No change	Increasing homogenization	
	Indicator species – invasive exotic plants	No key invasive exotic plant species on most plots	One to three key species per plot	Four or more key species per plot
	Indicator species – deer browse	No decrease in frequency of most browse-sensitive species	Decrease in frequency of most browsed species *or* increase in frequency of browse-avoided species	Decrease in frequency of most browsed species *and* increase in frequency of browse-avoided species
Function	Tree growth and mortality rates	Growth ≥ 60% mean and mortality ≤ 1.6%	Growth <60% mean or mortality >1.6%	
	Soil chemistry – acid stress	Soil Ca:Al ratio >4	Soil Ca:Al ratio 1–4	Soil Ca:Al ratio <1
	Soil chemistry – nitrogen saturation	Soil C:N ratio >25	Soil C:N ratio 20–25	Soil C:N ratio <20

Notes: Med–lg trees are ≥ 30 cm diameter-at-breast-height. Tree regeneration stocking index varies by park. Priority 1 pests are Asian longhorned beetle, emerald ash borer, and sudden oak death. Priority 2 pests are hemlock wooly adelgid, balsam wooly adelgid, beech bark disease, and butternut canker. See text for more details.

McWilliams *et al.* (2005) quantifies whether current seedling quantities are sufficient to restock a forest stand. We use this approach to assess minimum canopy tree stocking, which varies by park and dominant forest type.

Qualitative observation of *tree condition* for specific health and canopy foliage problems provides an early warning indicator of infestation, disease, or decline in a particular species, or within a region. Several exotic pests and pathogens are seriously impacting eastern forest composition or structure (eg hemlock wooly adelgid, *Adelges tsugae*; balsam wooly adelgid, *Adelges piceae*; beech bark disease, caused by *Cryptococcus fagisuga* and *Nectria* fungi; and butternut canker, caused by *Sirococcus clavigignenti-juglandacearum*), and several others pose an enormous threat if they advance into the region (eg Asian long-horned beetle, *Anoplophora glabripennis*; emerald ash borer, *Agrilus planipennis*; and sudden oak death, caused by *Phytophthora ramorum*). This metric assesses presence and, in some cases, severity of key pests and pathogens, and also qualitatively assesses canopy tree foliage problems.

Biotic homogenization is the process by which regional biodiversity declines over time, due to the addition of widespread exotic species and the loss of native species (Olden and Rooney 2006). Tracking the extent and magnitude of biotic homogenization provides a useful indicator of cumulative impacts on regional biological diversity. Among a group of sites, biotic homogenization can be calculated between site pairs as a simple ratio of species present at two sites over the total species present at either site (Jaccard's Similarity Index; Olden and Poff 2003). Alternatively, species' relative abundance can be included within a more complex similarity metric (Bray-Curtis Distance; Rooney *et al.* 2004). We will calculate metrics of similarity both for all species and for native species only, to better understand the causes and implications of change.

Carefully selected *indicator species* can be used to better understand the impacts of specific stressors on forest composition. The effects of *invasive exotic plant* species on natural systems have become a chief concern over the past 20 years, due to the growing number of species that are successfully exploiting and altering new habitats (Drake *et al.* 1989). We monitor the frequency of key exotic species that are highly invasive in northeastern forest, woodland, and successional habitats, as documented by the Invasive Plant Atlas of New England (IPANE, http://nbii-nin.ciesin.columbia.edu/ipane), the NatureServe Explorer database (www.natureserve.org/explorer), and studies within monitored parks.

In addition to impacts on tree regeneration, white-tailed deer browsing can severely impact composition of forest understories (Augustine and deCalesta 2003). Several studies have attempted to identify *indicator plants for deer browse* pressure, using plant population structure and relative plant abundance (Balgooyen and Waller 1995; Fletcher *et al.* 2001). Following the latter approach, we monitor the frequency of the common, highly visible, herbaceous species preferred by deer, concentrating on species that are known or predicted to be intolerant of deer browsing. We also monitor the frequency of species that are unpalatable to deer, and that are known to increase in abundance under heavy browse pressure. Frequency of these common species will vary regionally, so ratings will be assigned based on change between monitoring periods.

Metrics of ecosystem function

Finally, we evaluate three metrics of ecosystem function. Canopy *tree growth and mortality rates* provide an integrative metric of tree health and vitality. Decreased growth or elevated mortality rates may indicate a particular health problem, such as sugar maple decline (Duchesne *et al.* 2003), or may indicate a regional environmental stress (Dobbertin 2005). Distinguishing desired conditions for growth and mortality rates is not straightforward; these rates typically vary by site, by stand structural stage, and by tree species and canopy position. However, studies that compare tree growth in declining or recently dead trees with that of healthy trees report growth rates in the former to be reduced by 40 to 50% (Pederson 1998). To interpret growth rate, we analyze the growth of canopy trees in mature stands, as compared with regional or species-specific patterns documented by the Forest Inventory and Analysis (FIA) program of the US Forest Service. Mortality rate is assessed based on studies showing typical canopy tree mortality rates in late-successional forest range from 0.3% to 1.6% annually (Runkle 2000; Woods 2000).

Our *soil chemistry* metrics provide critical information on soil function that is altered by atmospheric deposition. The molar ratio of calcium to aluminum (Ca:Al) in soil water or soil has been developed as an indicator of *acid stress* to forest vegetation (Cronan and Grigal 1995). Atmospheric deposition acidifies soil, leaching important base cation nutrients (eg Ca^{2+}, Mg^{2+}, K^{+}) from the soil, and increases the availability of aluminum, which is a toxin. Sensitivity to acid stress varies among species; impacts to common eastern tree species have been noted at Ca:Al ratios of 4–5 (*Quercus rubra, Liriodendron tulipifera*), 2.5 (*Acer saccharum*), and >1 (several conifers; Cronan and Grigal 1995; Decker and Boerner 1997). Driscoll *et al.* (2001) suggest that the Ca:Al ratio can be used to judge ecosystem recovery after reductions in air pollution. We assess exchangeable Ca:Al ratios from soil samples taken from upper soil layers within the rooting zone.

Atmospheric deposition can also alter nitrogen (N) cycling. N is a limiting nutrient, necessary for plant growth, that historically has been retained within temperate forested ecosystems. Because atmospheric deposition has increased N inputs by 5- to 10-fold in the eastern US, there is concern that excess N may induce *nitrogen saturation*, exacerbating the effects of acidification (Aber *et al.* 1998). Changes in the carbon-to-nitrogen (C:N) ratio in soil are a primary indicator of forest nitrogen status and the impacts of atmospheric deposition. Aber *et al.* (2003) compiled data from sites across the northeastern US and discovered that nitrification increased sharply below a C:N ratio of 20–25. The Indicators of Forest Ecosystem Functioning (IFEF) database compiled data from 181 forest sites across Europe and found that, below a C:N ratio of 25, overall nitrate leaching was significantly higher and more strongly correlated to N deposition (MacDonald *et al.* 2002). The IFEF assessment found no significant differences in these relationships in deciduous as compared with coniferous forests.

Ideally, individual metrics will vary independently of one another, so that each metric provides unique information about ecological integrity. In practice, however, some metrics may be correlated. Preliminary data from Acadia National Park (described below) indicate that our two landscape metrics (forest patch size and anthropogenic land use) are negatively correlated. We have chosen to include both metrics because their correlation is not strong and because they should provide complementary information. For example, in some parks, relatively small forest patches may be interspersed with other natural community types, whereas in other parks, forest patches may be interrupted by anthropogenic land use. These two scenarios are likely to have different implications for ecological integrity. Most other metrics were not correlated in this preliminary dataset. We expected snag abundance to be correlated with CWD volume, but this was not the case here. Nor were our two measures of soil chemistry correlated. We will continue to explore correlations between metrics as we collect a larger and more robust dataset.

Does Acadia National Park have ecological integrity?

In 2006, we installed the first of four annual sampling panels at Acadia National Park (Figure 3). Plot locations were randomly assigned, by way of generalized random

Figure 3. *A field crew measures a forested plot at Acadia National Park.*

tessellation stratified sampling (GRTS; McDonald 2004). This equal-probability design allows for statistical inference while also providing balanced spatial coverage and flexibility for post-stratification of plots based on ecological system or other criteria, as needed over the long term (Tierney *et al.* in review). Pre-liminary data from these first 38 plots provide some indication of current status (Figure 4), but no trend data will be available until these plots are remeasured in 2010. This preliminary dataset indicates that forested ecosystems of Acadia National Park have retained ecological integrity across a variety of metrics, but that problems may exist in stand structure and soil chemistry.

Acadia retains integrity relative to our two landscape structure metrics. Forest patch size surrounding plots averaged about 1650 ha (±160 ha SE), which is well above desired conditions for maintaining habitat for birds, small mammals, and invertebrates. Within the 50-ha local neighborhood surrounding each plot, anthropogenic land use occurred on only about 2% (±1% SE) of land, well within the range considered "Good" (< 10%). This is fortunate, considering that Acadia National Park is a patchwork of natural areas interspersed with towns and other anthropogenic land uses.

Analysis of stand structural stage across the park indicates that only about 10% of plots exhibited late-successional structure, well below expected conditions for the dominant lowland spruce–hardwood ecosystem (≥30%). The forests in Acadia are still recovering from an intense fire in 1947, and it remains to be seen what full recovery will look like in terms of stand structure. Preliminary results for structural habitat provided by dead wood were mixed. Snags averaged 16% (±2% SE) of total tree stems, falling within the "Good" range (≥10%). However, the sample size for snags in medium and larger size classes (≥30 cm dbh) was too small to determine status in this first year of monitoring. CWD represented only about 6% of live tree volume (±1% SE), which is lower than expected (>15%). The status of these metrics should improve as stands mature.

Two of the five compositional metrics could be assessed at this time, and both of them were rated "Good". According to qualitative assessment of tree condition, most plots showed no evidence of key pests and pathogens, and minimal canopy foliage damage. Likewise, no key invasive exotic plant species were detected on most plots. Acadia's biologically isolated location on the Maine coast may offer some protection from invasive exotic species, but continual monitoring for early detection is warranted. Our sample size was insufficient for assessing tree regeneration at Acadia with our 2006 protocol, and we have subsequently increased the area sampled for this metric. Both the biotic homoge-

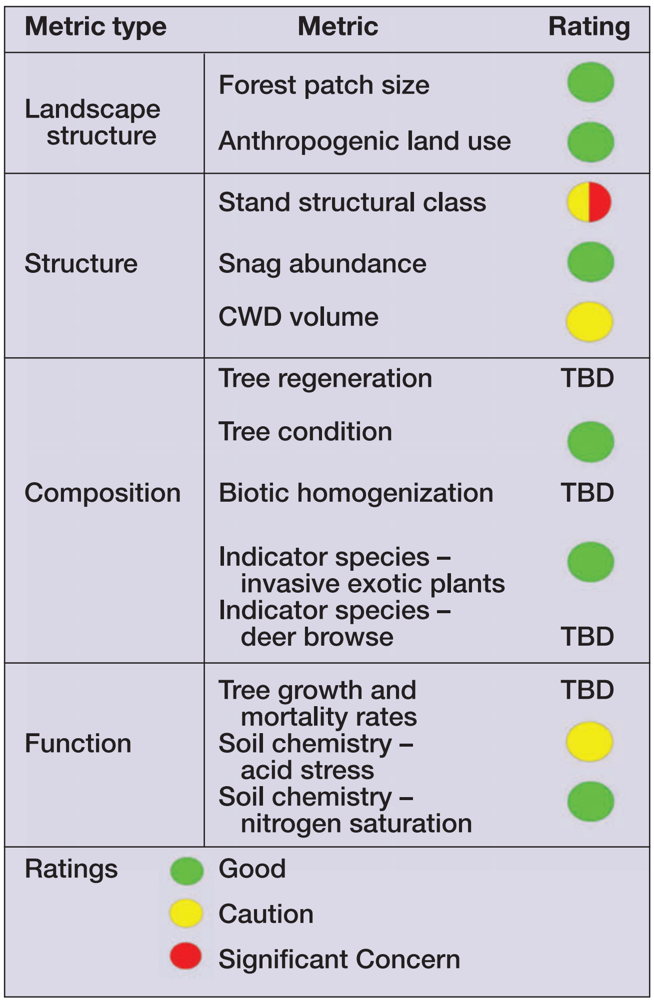

Figure 4. *The 2006 forest integrity ratings for Acadia National Park. TBD = to be determined after additional data are collected. Current knowledge is insufficient to distinguish "Caution" from "Significant Concern" for stand structural class. CWD = coarse woody debris.*

nization and deer browse indicator species metrics are evaluated based on change over time, and will be assessed after remeasurement of these plots.

Soil chemistry analysis showed mixed results. The average C:N ratio of the upper soil horizons was about 35 (±1.2 SE), safely within the "Good" range (> 25). However, average Ca:Al ratio was only 3.7 (±0.6 SE), indicating a potential soil acidification problem. The final functional metric – tree growth and mortality rates – is based on change over time and will be assessed after remeasurement.

Conclusions

Ecological integrity provides a useful tool for assessing and interpreting monitoring data in a way that is meaningful to many audiences, including policy makers and the public. Monitoring based on integrity should include elements of ecosystem structure, composition, and function that are expected or known to vary in response to agents of change that affect the monitored ecosystem. Assessment of ecological integrity is based on natural or historic variability. We have presented a suite of metrics designed to assess the status and trends in temperate forested ecosystems of the northeastern US facing a variety of anthropogenic stressors. We hope this approach may be useful to others, and we will continue to improve this protocol as more data become available.

Acknowledgments

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