Monitoring Ecological Resources within U.S. National Parks: Developing "Vital Signs" of Ecological Integrity for the Northeast Temperate Network

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Abstract—*The National Park Service (NPS) initiated a new "Vital Signs" program in 1998 to develop comprehensive, long-term monitoring of ecological resources within U.S. national parks. Vital signs (VS) are indicators, and are defined as key elements, processes or features of the environment that can be measured or estimated and that indicate the ecological integrity of an ecosystem. A core science team is working with the 11 parks of the Northeast Temperate Network (NETN) to identify appropriate regional and park-specific indicators of ecological integrity, and to develop criteria for assessing changes. The team identified VS representing the diversity of ecological systems and anthropogenic stressors within NETN parks at a range of ecological scales. In Phase 1, baseline inventories and analysis of threats provided information to build conceptual ecological models for four ecosystem groups – terrestrial, wetland, aquatic, and intertidal systems. In Phase 2, the core science team developed a list of more than 100 potential VS. This preliminary list was peer-reviewed through workshops, from which a final list of 22 high priority VS, with 104 associated potential measures, was developed. In Phase 3, protocols will be developed for each VS measure. Statistical power analysis and cost assessment will be an integral part of Phase 3 in order that the final set of measured VS produce reliable inference within cost constraints of NETN. Standard summaries of statistical trends in VS measures will be compiled. Importantly, each measure will also have a rating scheme to allow integration of VS into an overall ecological integrity rank (A-D) for particular occurrences of an ecosystem. These ranks, currently used by NatureServe and the Network of Natural Heritage Programs, provide an important communication tool for managers. An example is presented for jack pine woodland in Acadia National Park.*

Introduction

Recognizing the need for comprehensive, long-term monitoring of ecological resources within the U.S. National Park System, the National Park Service (NPS) undertook a major new initiative in 1998 to develop a program for long-term monitoring of "Vital Signs," or indicators, of ecological integrity within the parks. Vital signs (VS) are key elements, processes, or features of the environment that can be measured or estimated and that indicate the ecological integrity of an ecosystem. This Inventory & Monitoring (I&M) program is being implemented within 270 parks, which have been grouped into 32 park networks, using a consistent framework and process (Fancy, this proceedings; Gross, this proceedings). A core science team is working with the 11 parks of the Northeast Temperate Network (NETN) to identify appropriate regional and park-specific indicators and measures of ecological integrity and to establish protocols for their measurement (table 1). As with other NPS Networks, the NETN team has focused on identifying indicators representing the diversity of ecological systems and anthropogenic stressors within NETN parks at a range of ecological scales. The challenge has been to

Table 1. Parks included in the Northeast Temperate Network, showing park name, state, and park size (in acres). NP = National Park, NST = National Scenic Trail, NHP=National Historical Park, NHS=National Historic Site, NPA = National Park Area. Only the northern section of the Appalachian NST (from Maine to Pennsylvania) lies within the NETN. Other networks assess the southern sections.

Park Name	State	Size (acres)
Acadia NP	Maine	47,498
Appalachian NST	Maine-Georgia	85,036
Boston Harbor Islands NPA	Massachusetts	1,465
Marsh-Billings-Rockefeller NHP	Vermont	643
Minute Man NHP	Massachusetts	967
Morristown NHP	New Jersey	1,707
Roosevelt-Vanderbilt NHS	New York	775
Saint-Gaudens NHS	New Hampshire	150
Saratoga NHP	New York	3,392
Saugus Iron Works NHS	Massachusetts	9
Weir Farm NHS	Connecticut	74

identify a coherent set of indicators that cover the range of ecological resources and stressors found in the network within the budgetary constraints of the program, and that can be meaningfully compared to other NPS networks, as well as indicator programs outside the NPS. NETN Vital Signs must also provide information that allows park managers to respond when changes to park ecological integrity are detected.

The need to compile a coherent set of indicators and measures that encompass essential aspects of ecosystem structure and function and contribute to an adaptive management program has led to increasing interest in the development of measures or indices of ecological integrity (Karr and Chu 1995; Harwell and others 1999; Andreasen and others 2001, Young and Sanzone 2002; Parrish and others 2003). At the outset, understanding the dynamic nature of park ecosystems and the consequences of human activities is essential for management decision-making aimed to maintain, enhance, or restore the ecological integrity of park ecosystems and to avoid, minimize, or mitigate ecological threats to these systems (Fancy, this proceeding). Although our current understanding of these dynamics is far from complete, indices of ecological integrity should allow managers to discriminate between changes in indicators and measures that fall within the bounds of normal system dynamics from those that require a management response (Woodley 1993).

The overall process for developing the NPS VS program has been described elsewhere in this proceeding (Fancy, this proceedings, Gross, this proceedings). Briefly, the I&M Vital Signs Program incorporates a three-phase approach: Phase 1) define goals and objectives; begin the process of identifying, evaluating and synthesizing existing data; develop draft conceptual models; and complete other background work; Phase 2) prioritize and select VS and develop specific monitoring objectives for each park and the network; and Phase 3) develop detailed plans to implement monitoring, including the development of sampling protocols, a statistical sampling design, a plan for data management and analysis, and expectations for reports and other presentation of results. Herein we focus primarily on the NETN Phase 2 process – the prioritization and selection of Vital Signs – but we also briefly summarize our efforts in Phase 1 to develop conceptual ecological models, which provide a foundation and summary tool for indicator selection, and preview our next steps in Phase 3.

Phase 1: Conceptual Modeling

During the initial phase of the VS program, baseline data assessments are compiled, including results from 12 baseline inventories that the U.S. Geological Survey (USGS) I&M Program provide for each park. These include species group inventories, such as mammals, birds, herptiles, and exotic species, as well as comprehensive park mapping of ecosystems and communities through the USGS Vegetation Mapping Program (biology.usgs.gov/npsveg/). These maps are based on the federal U.S. National Vegetation Classification standards (FGDC 1997) and NatureServe Ecological System classification (Comer and others 2003). When all 11 parks are completed, these maps will provide a consistent ecosystem inventory across the Network. Park staff also completed a threats assessment 2001 to 2003 to assist in prioritizing VS. These inventory data provided the basic information needed to develop conceptual models that could be used to communicate the primary threats, stressors, natural resource priorities, and ecological condition within Network parks, and ultimately identify indicators of ecological integrity.

Conceptual ecological models are useful tools for summarizing and communicating ecological knowledge. Our intent in building these models is to predict linkages between ecological resources, key stressors, and elements of ecological integrity, and to use this information to select appropriate Vital Signs. These models should facilitate development of indicators that are a useful subset of measurable ecosystem features or processes that are particularly information-rich, in that their values are indicative of the integrity of the larger ecological system to which they belong (Parrish and others 2003).

Within NETN, we employed a conceptual model that includes both stressor (threats) and ecological condition

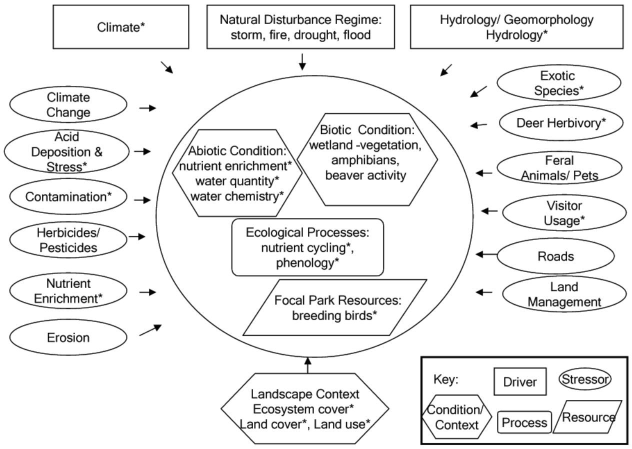

Figure 1. Example of a conceptual model for the wetlands ecosystem group. The key shows the major categories that organize the various vital signs. Similar models exist for terrestrial, aquatic and intertidal, and for each park. Stressors that are asterisked, and all vital signs inside the circle, were selected as part of the final Vital Signs list (see table 3).

components, visually depicting how system components interact. An accompanying narrative provides specific details of our understanding of the systems. We chose a hierarchical approach to model development, beginning with a general model for each of four key NETN ecological system groups --terrestrial, wetland, aquatic and intertidal ecological systems (figure 1). These general models identify key ecosystem drivers, stressors, ecological processes, elements of ecosystem condition and landscape context, and focal park resources within each of these four major system groups. The categories for our model include 1) Drivers, Stressors, and Landscape Features, 2) Ecological Condition, and 3) Focal Park Resources. Ecosystem drivers are major external forces such as disturbance regimes, hydrology, geomorphology, or climate that have large-scale influences on natural systems. Stressors are natural or anthropogenic forces of change acting upon ecosystems. Landscape features include landscape context, which refers to features of the surrounding environment that affect the ecosystem of interest at the "landscape" scale. Ecological condition in these models is comprised of elements biotic and abiotic condition, usually at the "stand" scale, such as population trend of selected species, or air quality. Ecological processes such as nutrient cycling or phenology are also considered as elements of ecological condition. Finally, these models include focal park resources that, by virtue of their special protection, public appeal, or other management significance, have paramount importance for monitoring regardless of their relevance to ecosystem integrity. These models and associated narrative are continually updated as new information about the systems becomes available.

Phase 2: Selection of Vital Signs

We prioritized and selected potential Vital Signs using a sequential peer review process. A core science team of six staff (representing expertise in forest ecology and vegetation science, aquatic ecology, wetland ecology, amphibians, ornithology, biogeochemistry, conservation biology, and ecological data management) first drafted a list of over 100 potential VS representing the three major categories identified in the conceptual models. This was a comprehensive list -- targeted to ecological systems present within NETN—that spanned spatial, temporal, and biological scales of organization.

We reviewed and prioritized this list with a multi-stage process, comprised of 1) initial review by the NETN core science team, which initiated the list of VS and criteria for selection (table 2); 2) external peer-review by a group of more than 40 scientists and park managers; 3) review by the NETN Technical Steering Committee, composed of both external scientists and NPS staff., 4) additional review by NETN core science team, and 5) National I&M Program Review and Approval (in process).

This review process has, to date, generated a list of 22 VS (table 3). In the process of selecting the VS, we also identified specific measures for quantifying each VS (table 3). Ongoing review will ensure a coherent list of VS that are responsive to park needs, fiscally reasonable, and scientifically sound.

Phase 3: Protocols and Ecological Integrity Assessment

NETN will begin Phase 3 during fall 2004. The primary focus of Phase 3 is to develop specific measures and protocols for each VS. We plan to emphasize four features – 1) consider tiers of VS measures, 2) assess how bundling and considerations of effect size on VS measures affects costs, 3) development of standard summaries of statistical trends in VS measures, and 4) use of an ecological integrity scorecard. First, we will consider a tiered approach to the measures and VS. Not all VS are equally accessible and measurable. A first tier of measures may rely on remote sensing imagery and rapid ground assessments. A second tier may rely on more detailed monitoring, perhaps requiring greater temporal and spatial sampling.

Table 2. Summary of 4 main criteria used to screen potential list of vital signs during the Phase 2 peer review process.

1. Management Significance & Utility	2. Ecological	3. Feasibility of Relevance	4. Response Implementation Variability
Relevant to assessment questions	Clear linkage to ecological function or integrity or specific resource	Availability of standard, well-documented methods	Low or controllable measurement error, high repeatability of measurement, quantitative & objective
Sensitive to and/or indicative of stress	Anticipatory	Lack of sampling impacts on indicator	Temporal variability (both within and between seasons) predictable and/or described
Not redundant unless improves performance	Indicative of status of other resources	Rapid, cost-efficient and/or can be bundled with other indicators for measurement	Spatial variability understood or controllable
Relative to determining quantitative thresholds for condition		Baseline data available	Sufficient discriminatory ability, both along a long-term condition gradient and in terms of statistical power
Linked to management actions		Easily measured with little equipment or specialized knowledge, and large sampling window	
Widely applicable (geographic, across ecosystems, and for multiple purposes)		Long-term data management feasibility	

Second, we will consider a bundled approach to protocol development. Rather than developing protocols and estimating costs for each VS independently, we plan to approach the problem conceptually as it will eventually be tackled in the field, that is, by field crews measuring multiple VS on co-located plots to the full extent possible. Thus we are proceeding into Phase II as follows: (1) all VS will be represented by one or more measure, (2) multiple measures at co-located sites will represent "bundles" (which may cross multiple vital signs) that will be recorded by field crews trained to measure the particular bundle of VS (for example, forest mensuration, soil chemistry, amphibians, and invasive understory plants could be the focus of the "forest health bundle," (3) the first measure selected for a given bundle includes all base costs for travel to the plot; measures subsequently added to a bundle assume only incremental cost associated with adding them to bundle (in many cases no or little additional cost), (4) overall costs are calculated based on cost of an individual measurement * number of measurements needed to detect change (assuming statistical errors type I = type II = 0.10) * number of parks where measured X number of ecosystems with each park for which inference is to be made, and (5) sampling designs represented by repeat measurements of permanent plots. Some VS measures will be essentially censuses (for example, land cover change analysis) and thus will involve a single "up front" cost. Significant decisions have yet to be made on effect size sought for detection for each VS measure, as these dramatically affect sample size and hence overall cost. By proceeding with an assessment of potential VS measures in the manner described about we will track the accrual of monitoring costs and terminate the VS measure selection process once available financial resources for conducting the monitoring are allocated.

Third, we will address how to perform standard synthesis of VS trends. Because VS data will consist of repeated measures of continuous metrics, we will perform standard summaries of statistical trends in VS measures. These will include aggregate trends among related indicators and aggregate trends among indicators within particular ecosystem types. Because many VS will be measures at co-located sites, correlations among them will also permit general inferences to be made about potential causes of ongoing trends observed in the VS.

Fourth, we will develop the use of ecological integrity ranks. These tools are needed to take a program from collection of field data for indicators and measures to interpretation of those values that allow managers to determine whether or not ecological integrity is changing in the parks. This interpretation does not supersede the precise analysis of the field data themselves, but does inform the intensity of their sampling and the response of managers to changes in those data. In other words, a good monitoring program needs to set objectives for measuring indicators based on the best current understanding of how ecological systems work, baselines that include reference conditions from known high quality sites, and

Table 3. Northeast Temperate Network VS list, August 2004. Vital Signs (VS) are presented within the NPS Vital Signs Program national framework to create reporting consistency among networks. Potential measures in italics will be investigated for inclusion during Phase 3 but require further evaluation. No. of Parks indicates the number of NETN parks within which each VS will be monitored.

Level 1	Level 2	Network Vial Sign Name	Potential Measures	No of Parks
Air and Climate	Air Quality	1. Ozone	Atmospheric ozone concentration (synthesize existing data), (foliar injury to indicator species)	7
		2. Acidic deposition & stress	Wet and dry deposition rates (synthesize existing data), soil nitrification, soil base cation availability, soil Ca:Al ratio, streamwater ANC, streamwater nitrate concentration (Total deposition rates including occult)	7
		3. Contaminants	Heavy metal deposition (synthesize existing data)	11
	Weather and Climate	4. Climate	Air temperature, precipitation by type, relative humidity, total solar radiation, wind speed, wind direction, snow water equivalent, snow depth	11
		5. Phenology	First flowering of sensitive plant species, first amphibian call dates, length of growing season, ice out/in dates for lakes and ponds	5
Geology and Soils	Geomorphology	6. Shoreline geomorphology	Relative surface elevation, shoreline change	2
Water	Hydrology	7. Water quantity	Water depth, water duration, lake levels, streamflow, groundwater levels/inputs, spring/seep volume, sea level rise	11
	Water Quality	8. Water chemistry	Stream water nitrate, stream alkalinity/ANC, water temperature, % dissolved oxygen, specific conductance, pH, turbidity, Secchi disk, color	11
		9. Nutrient enrichment	Turbidity, #septic systems in and near park, algal biomass, total and dissolved phosphorus, amount fertilizer used within park, residential density near park	11
		10. Streams - macroinvertebrates	Diversity of selected communities and subcommunities	9
Biological Integrity	Invasive Species	11. Exotic Species- early detection	Presence/absence, extent, distribution	11
	Focal Species or Communities	12. Intertidal – vegetation	Diversity of salt marsh and rocky intertidal community and subcommunities, exotic species extent	2
		13. Wetland – vegetation	Diversity of community and subcommunities, exotic species extent, beaver activity	11
		14. Forest - vegetation	Community diversity (all layers), tree species, rates of mortality and regeneration, stand structural dynamics, tree basal area by species, canopy condition, snag density, coarse woody debris volume; percent exotic species	9
		15. High elevation - vegetation	Diversity of community and subcommunities; percent exotic species	1
		16. Fish – lakes and streams	Diversity of community and subcommunities; percent exotic species.	6
		17. Breeding birds	Diversity of forest, high elevation, grassland/scrub, old-field, and coastal communities and subcommunities	10
		18. Reptiles and amphibians	Diversity of wetland/vernal pool communities and subcommunities (red-backed salamander abundance in forests)	10
		19. White-tailed Deer herbivory	Browse intensity in forests	9
Human use	Visitor and Recreation Pressure	20. Visitor usage	Number of visitors by location and activity, trampling impacts, soil erosion	11
Ecosystem Pattern and Processes	Land Cover Land Use	21. Land cover / Ecosystem cover	Change in area and distribution of ecological systems (including intertidal communities) within park and adjacent landscape, patch size distribution, patch connectivity, patch fragmentation, extent of major disturbance, ecological integrity index by ecological system	11
		22. Land use	Road network extent, nearby housing development permits, proportion of nearby lands in various categories of human uses, % impervious surface in watershed, nearby human population density, landscape buffers	10

the historic range of variability expected or permissible in the measures. Indeed, if restoration of sites in parks is being considered, this kind of information is especially critical. Information of this kind can lead to indicator thresholds based on "normal' or "natural" benchmarks with clearly identified thresholds, along with developing protocols for those measures to ensure consistent field measurements and documentation. A subsequent step is to then provide a scorecard matrix by which the measures are rated and integrated into an overall assessment of the ecological integrity of the system(s) in a park or across the network.

In order to synthesize and summarize VS in a meaningful fashion that can be communicated to a diverse audience, VS and Measures will require ratings for levels of overall ecological condition. These ratings can be integrated into an overall ecological integrity rank, similar to the "element occurrence ranking procedure" developed by NatureServe and the Network of Natural Heritage Programs (NatureServe 2002, Parrish and others 2003). A series of steps to generate an Ecological Integrity Rank will be taken, as shown in figure 2. After the VS and measures are prioritized (fig. 2, steps 1 and 2) and a final list is generated (as in table 3), they can be linked to specific ecosystem targets (fig. 2, step 3). In this way, measures are tailored to the systems being assessed. By compiling information from baseline studies in the park, reference sites outside the park, and understanding the historic range of variability of VS and measures for each system, it may be possible to rate the field values that are collected using these protocols during the monitoring program (fig. 2, step 4). Ratings range from Very Good to Poor, and are a judgment about the expected range of values that define better or worse conditions of ecological integrity. The intensity of sampling and expectation for detecting trends may be derived from our understanding of these sources (fig. 2, step 5). Note that for each sample period, the field values are recorded and stored independently of the ratings. The roll-up of these ratings provides the basis for the overall Ecological Integrity Rank (fig. 2, step 6) for specific occurrences (or sites) and across the park or network.

An illustration of this process is shown for the rare Jack Pine Woodland type at Acadia NP. This community is a rare NVC association found within the Laurentian-Acadian Acidic Rock Outcrop system. An ecological integrity rank is developed by first linking the VS and measures from table 3 to this Ecosystem (table 4), as illustrated in figure 2, step 3. Mapped occurrences of this jack pine woodland association are visited, and measures associated with all applicable vital signs will be collected. Field values of each measure will be assigned a rating. Ratings can then be "rolled-up" into an overall Ecological

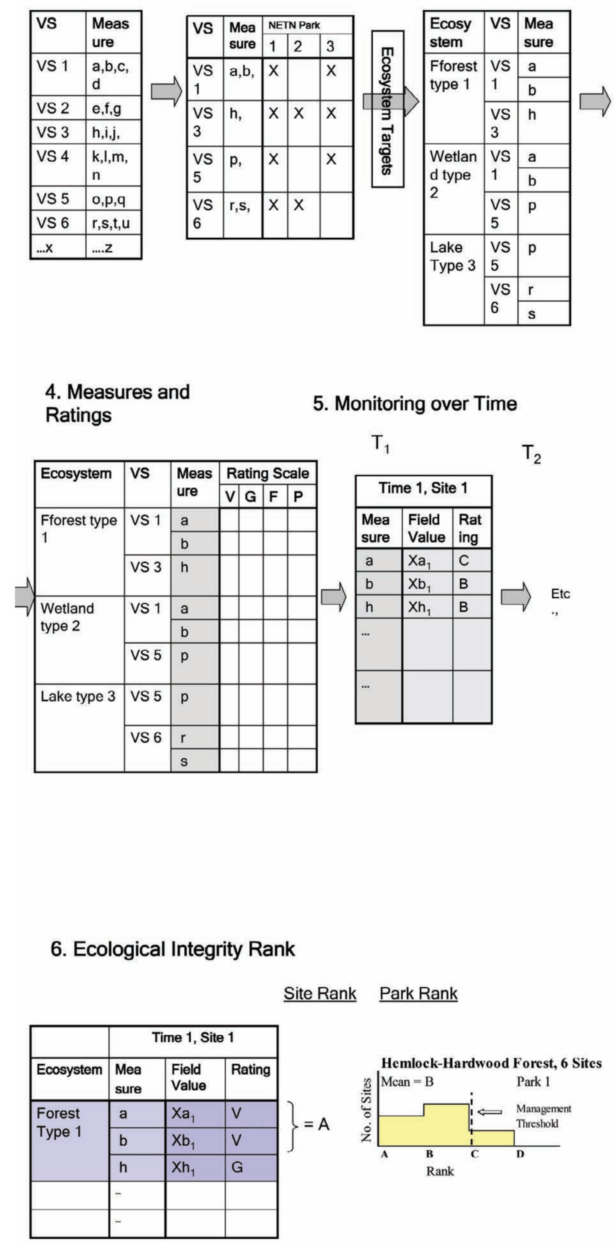

Figure 2. Illustration of ecological integrity rank methods based on vital signs and measures. Steps 1 – 2 show development of vital signs and measures, step 3 links a subset of them to specific ecosystem targets, step 4 develops rating for each measure specific to the ecosystem, and step 5 shows how field values for each measure are stored independent of the rating for that measure. For example, VS 1 = Forest -- vegetation. Measure a = exotic species percent cover. Forest Type 1 = Hemlock-Hardwood Forest. Ratings for measure a = Very Good < 1 % cover exotic species; Good= 1-4 % cover; Fair = 5-20%; Poor = >20%. Thus, a field value for a stand of Hemlock-hardwoods forest with 3% exotic species cover generates a rating of Good. In Step 6, combining all ratings for measures of a system through a rule-based approach generates the Ecological Integrity Rank for the occurrence (A=Excellent, B=Good, C=Fair, D=Poor). Ranks across a park can be averaged into an overall park rank, or displayed as a histogram, with management thresholds established; if individual stands fell below this threshold, management action would be taken.

Table 4. Jack Pine Woodland Ecological Integrity Rank table. Table displays the vital signs and measures applicable to assessing the ecological integrity of the Jack Pine woodland. Field Values are collected based on standard protocols. A rating is assigned to the Field Value based on the Rating Scale, which summarizes the range of values expected for a measure. Ratings for only a few measures are shown, for reason of brevity.

Category	Vital Sign	Measure	Field Value, T1	Rating, T1	Rating Scale Very Good	Good	Fair	Fair Fair
Condition	Ecosystem Cover	Patch size in acres			>50 acres	20-50 acres	5-20 acres	3-5 acre
	Consumptive Use	Degree of anthropogenic disturbance (e.g. logging, recreation)	5%	Good	Minimal; affecting < 1% of community	Minor; affecting < 10% of community	Significant, affecting 10-50% of community, severe impacts may be evident, but recovery possible	Extensive; affecting > 50% of community, poor potential for recovery, if at all
	Extreme Disturbance Events	Natural disturbance regime (fire and/or blowdown)			Not shown	Not shown	Not shown	Not shown
	Forest—Vegetation	Basal area / canopy cover by species			Not shown	Not shown	Not shown	Not shown
		Cover of exotic species	2%	Very Good	Absent	Present, but in low numbers (1-5%)	In abundance (5-20% cover)	Abundant (> 20%)
Land-scape Context	Land Cover / Ecosystem Cover	Patch size distribution - Edge to interior ratio			Not shown	Not shown	Not shown	Not shown
		Patch connectivity			Not shown	Not shown	Not shown	Not shown
		Patch fragmentation			Not shown	Not shown	Not shown	Not shown
	Land Use	Proportion of nearby lands in various categories of human use (e.g., develop-ment, roads, logging, fire suppression)			Not shown	Not shown	Not shown	Not shown

Integrity Rank, using a Scorecard value (A-D), allowing the rank to be displayed on the map (for roll-up methods see NatureServe 2002). Only two sets of polygons have been visited at this time to allow a rank to be assigned (fig. 3). Future fieldwork will focus on remaining occurrences, once the protocols for the measures are in place.

Conclusions

Selection of Vital Signs by NETN during Phase 2 of the NPS I&M program was dependant upon conceptual ecological models developed during Phase 1 of this program. These conceptual models help demonstrate linkages among ecological resources, stressors, and potential VS across the four major ecological system groups (terrestrial, wetland, aquatic, intertidal).

NETN found the sequential peer-review process, from core science team to external science partners and internal technical committee review, to be useful in developing a comprehensive set of VS. This process allowed us to test our assumptions, and expand scientific and technical input. The end result is a robust list of VS. Park participation in all stages ensured a good link between VS selection and management goals.

Our next steps, in Phase 3, are to set objectives, develop specific protocols based on bundling of VS measures and standard trend analysis, and develop ecological integrity ranks. These steps will be challenging, requiring careful attention to the role of baselines, reference conditions, and historic range of variability for measures of these dynamic sets of ecosystems. These VS need to be integrated into a process of adaptive management, whereby trends in VS can be communicated to managers, scientists, conservationists, policy-makers, and the public. The development of ecological integrity ranks to summarize VS trends should help provide the needed link between monitoring and management decision-making aimed at maintaining, enhancing, or restoring the ecological integrity of park ecosystems.

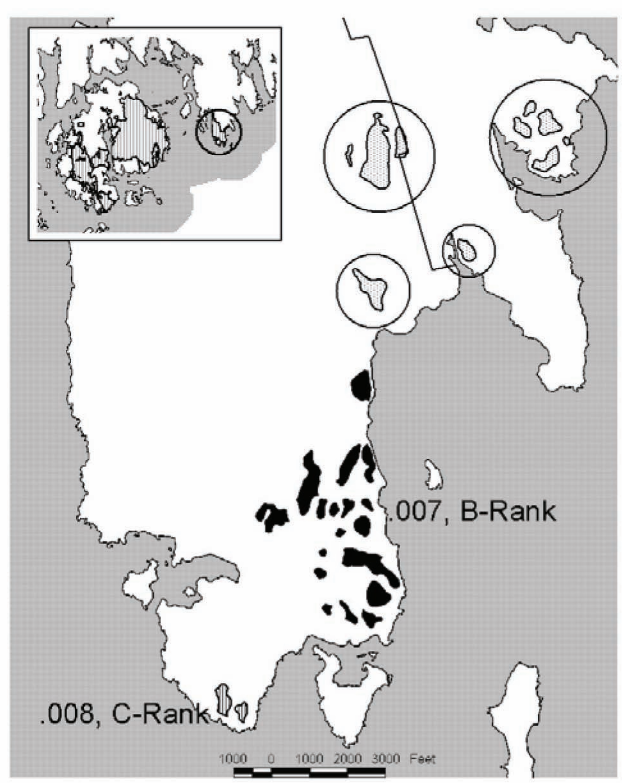

Figure 3. Map of Schoodic Peninsula, Acadia National Park, showing the occurences of Jack Pine Woodland, a part of the Laurentian-Acadian Acidic Rocky Outcrop system. Groups of polygons (in black and in vertical shading) are treated as separate occurrences. Each occurrence has been assigned an ecological integrity rank, based on the ratings for the field values for each measure (see table 4). Clusters of polygons that have been circled represent other occurrences that have not been field-visited, so they have not yet been assigned an overall ecological integrity rank. Inset shows the boundaries of Acadia NP, Maine, with the Schoodic Peninsula area circled.

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Acknowledgments

We want to especially thank Andy Cutko of the Maine Natural Areas Program, who allowed us to use his jack pine woodland table and figure. We thank members of the Northeast Temperate Network Technical Steering Committee who have participated in the review of the vital sign selection process, including Sam Droege, David Manski, David Hayes, Christopher Eagar, Wayne Millington, Tonnie Maniero, Mary Foley, Charles Roman, and Beth Johnson. We also thank the many participants of the first NETN Vital Signs review meeting at Acadia National Park.