National Park Service
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Natural Resource Stewardship and Science

The Ecological Integrity Assessment Framework

A Framework for Assessing the Ecological Integrity of Biological and Ecological Resources of the National Park System (Version 1.1)

Natural Resource Report NPS/NRSS/BRD/NRR—2018/1602

ON THE COVER
Photos of Grand Teton National Park, Badlands National Park, and North Cascades National Park (© NPS Photos)

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Abstract

This document provides an overview of the ***Ecological Integrity Assessment Framework***, a methodology to guide planning for the conservation of biological and ecological resources in U.S. National Parks. The framework is proposed as a tool for the National Park Service, Biological Resources Management Division, in pursuit of its goals to develop service-wide products that improve management of biological resources in parks, and maintain a broad ecosystem-based framework for park management. The Ecological Integrity Assessment Framework combines aspects of the conservation planning processes developed by NatureServe and The Nature Conservancy; and rests on established ecological theory as well as on the experiences of these two and many other conservation organizations worldwide. The document identifies those programs of the National Park Service for which the proposed methodology would provide a complementary or significantly expanded set of tools to guide the conservation of biological and ecological resources. It then summarizes the core concepts of the methodology and describes its key elements. It concludes with recommendations on how the National Park Service might further explore the methodology and its potential for application throughout the Service.

I. Introduction

The National Park Service (NPS) manages all natural resources in its units. These include, and are generally distinguished as atmospheric, hydrologic, geologic, pedologic, ecological and biological resources. The NPS also manages for resource-based values such as natural sound, night skies and animal health, and for critical ecological processes such as evolution, natural wildfire and water flow. NPS managers seek to achieve a standard of "natural" conditions defined by a "lack of human dominance" (NPS 2006). But natural resource management is complicated by cultural and visitor needs. In many units, goals to manage natural resources compete with goals for cultural features. In these situations, natural resources may be intentionally managed in a simplified state, such as maintaining a single seral stage of a plant community at a historic site. The NPS Organic Act of 1916 emphasizes the preservation of resources for future generations, and NPS Management Policies (NPS 2006) direct managers to favor the long term conservation of resources over visitor and recreational needs where necessary. Park managers must also work to maintain resource condition in the context of potentially overwhelming stressors – pervasive contaminants, landscape fragmentation, biological invasions and climate change. These, in concert with the emerging understanding that Native American activities long affected North American ecosystems prior to European colonization, sometimes test current definitions and standards for "natural" conditions. A separate standard directs Park management to address "impairment." The NPS defines impairment as "an impact that in the professional judgment of a responsible NPS manager, would harm the integrity of park resources or values and violate the 1916 NPS Organic Act's mandate that park resources and values remain unimpaired (NPS 2006)." To date, the NPS has not adopted a quantitative framework by which we can assess, with any confidence, whether we properly manage biological and ecological resources either to achieve "natural" conditions or to minimize impairment.

The Biological Resources Division (BRD) of the National Park Service developed its first 5-year strategic plan in 2006. This plan recognizes the major environmental, social, and political challenges facing the NPS, and emphasizes the need to apply new tools and approaches to better achieve science-informed natural resource management. The BRD strategic plan sets a primary goal for the Division to anticipate and respond to the current and emerging needs of the parks, the park system, and NPS leadership. To accomplish this for innumerable and complex biological and ecological resources across the National Park System, the BRD plan identifies the need to (1) develop service-wide products that improve management of biological resources in parks; and (2) maintain a broad ecosystem-based framework for park management while working on programs that deal with discrete biological resource issues. The present document, *Ecological Integrity Assessment Framework* (EIAF), is part of BRD efforts to address these needs.

The ***Ecological Integrity Assessment Framework*** provides a methodology to support planning and management for the conservation of native biological diversity in National Park Service units, and the enhancement of ecological resiliency in the face of climate change and other stresses.

Ecological integrity is "the ability of an ecological system to support and maintain a community of organisms that has a species composition, diversity, and functional organization comparable to those of natural habitats within a region. An ecological system has integrity, or a species population is viable, 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, Braun et al. 2003).

Specifically, the ***Ecological Integrity Assessment Framework*** guides the development of metrics, measures and strategies for ecological resource management within any individual Park unit through three steps (Figure 1):

1) ***Identifying What's Important:*** *Determining the suite of biological and ecological resources that need to be conserved*. This step includes identifying the geographic scope of the planning effort; identifying the suite of biological and ecological resources of potential concern to the Park unit; identifying stressors known, suspected, or anticipated to affect these resources; and selecting a sub-set of the unit's ecological resources on which to focus management (herein termed *focal ecological resources*).
2) ***Determining How It's Doing:*** *Developing metrics to characterize the integrity of the focal ecological resources*. This step includes developing a conceptual model of the ecology of each focal resource and identifying the key ecological attributes for each focal resource, on which to further focus management attention; identifying indicators for these key attributes and an ecologically acceptable range of variation for each indicator; and assessing the status of each focal ecological resource based on indicator data.
3) ***Stating What We Want:*** *Shifting to the management of focal ecological resources*. This step includes identifying desired conditions for each focal ecological resource based on its key ecological attributes (and their indicators); identifying potential stressors affecting the status of each focal ecological resource; setting a timeline for action to establish or ensure the continuity of desired conditions; and establishing performance metrics or benchmarks with which to evaluate these actions.

It is critical that the implementation of this framework is be guided by careful attention to existing ecological knowledge. In turn, the framework helps identify crucial gaps in that knowledge for which additional research is needed.

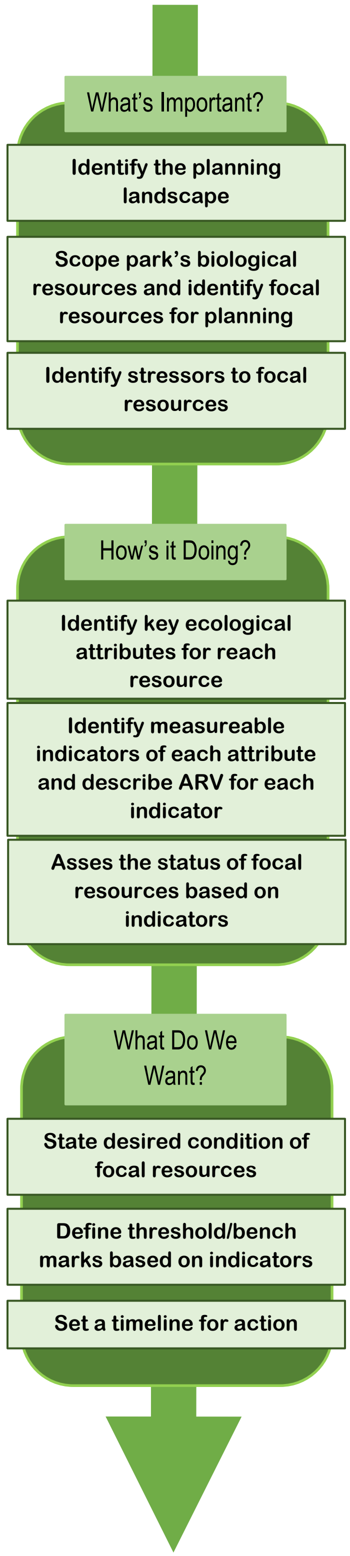

Figure 1. The Ecological Integrity Assessment Framework guides the development of metrics, measures and strategies for ecological resource management within any individual Park unit through three steps.

NPS Programs and Park Needs

This framework can be used in part or whole as a tool to support work through service wide programs and park projects. These include:

NPS Planning

The NPS seeks to implement a hierarchical planning structure for individual Park units. This begins with the direction provided in a unit's establishing legislation, and developed in a Foundation Document. This document identifies and analyzes the resources and values that are fundamental to the park's purpose or are otherwise important to park planning and management. These efforts often address biological and ecological resources in general terms, such as "vegetation" and "wildlife.' Next, the General Management Plan (GMP) defines a broad direction for resource preservation and visitor use in a park, and serves as the basis for park decision-making. It sets the long-term direction for management through goal statements for the desired conditions of park resources and visitor experiences. Program Management Plans then expand on the GMP, identifying strategies to achieve the desired outcomes for resources and visitor experience.

Each park unit prepares five-year Strategic Plans and Implementation Plans based on its Program Management Plans, identifying the highest-priority strategies and implementation objectives for maintaining and/or restoring the park's desired conditions over short time periods. Through this structure, NPS managers identify resources, management directions, and desired conditions for identified resources. This document helps planners address the breadth of ecological resources and provides a tool to develop metrics and meaningful desired conditions for resources.

Performance Management

The NPS reports to the President and Congress in compliance with the Government Performance and Results Act (GPRA). This reporting addresses progress toward goals developed for species, environmental quality and "land health." The reporting addresses progress toward both long-term outcomes, or desired future conditions or intermediate outcomes, reflective of specific incremental actions.

Guidelines for both national planning and reporting are helping the NPS move toward condition-based management. This shift requires articulating resource management outcomes based on measurable desired resource conditions. This document presents a process to evaluate the resource dimension of natural resource desired conditions.

Resource Impacts in Parks

It is impossible to plan for all resources or potential management decisions. Because of this, managers often respond to resource impacts that are not specifically addressed in plans. Impacts are significant positive and negative effects, defined in terms of human (including manager) values that result from events or interactions involving a) resources, b) management interventions and c) stakeholder interactions with respect to resources. Also, impacts are a subset of the most important effects or interactions between people and resources. The EIAF provides a process to identify the range of related resources and processes that are influenced by impacts.

Biological Resources Programs

The BRD currently addresses NPS and park management concerns for biological and ecological resources through programs in Wildlife Health; Threatened and Endangered Species; Integrated Pest Management; Invasive Plant Management; and Ecosystem Management and Restoration. The EIAF provides an approach to integrating these concerns in support of the Division's Mission.

Natural Resource Condition Assessments

The NPS Natural Resource Condition Assessment (NRCA) Program provides parks with an interdisciplinary, semi-quantitative evaluation of current condition status, critical data gaps, and resource condition influences relative to a strategic subset of important natural resources and indicators. They also summarize overall resource conditions by park sub-areas of greatest management interest (e.g., by watersheds, habitat/ecosystem types, or management zones).

Inventory & Monitoring Program

The NPS Inventory and Monitoring (I&M) Program collects, organizes, and makes available natural resource data; and contributes to the Service's institutional knowledge by helping transform data into information through analysis, synthesis, and modeling. These efforts address the Program's mission to "improve park management through greater reliance on scientific knowledge." The Program has developed a set of "vital signs" or indicators of resource status and trends for each of its 32 park networks. This document complements the I&M methodology by identifying metrics for vital signs. Additionally, this document provides guidance for identifying useful indicators for broadly defined vital signs such as "upland vegetation," and for ensuring that species are incorporated into systems-level vital signs. The EIAF also provides a methodology to 1) apply NPSpecies data to planning and assessment, and 2) establish criteria to distinguish high integrity from low integrity (i.e., "impaired") conditions for individual vital signs.

Emerging Management Approaches

Greater emphasis needs to be placed on learning in natural resource management, as adaptive resource management replaces more traditional approaches to resource management. Adaptive management of biological and ecological resources results in conservation actions that incorporate measurable hypotheses, gather appropriate information, and periodically evaluate the findings. Adaptive management is thus a specific type of resource management with a scientific feedback loop built into the management process. The EIAF is explicitly a framework for adaptive management.

The NPS, along with other conservation organizations, must increasingly consider both the spatial and temporal scale of their work in light of global change. Efforts to cooperatively preserve biological and ecological resources will benefit from the use of a shared framework for setting goals, analyzing resources, guiding decision-making, and measuring outcomes. The EIAF is such a shared framework.

Benefits of the Ecological Integrity Assessment Framework

The Ecological Integrity Assessment Framework derives from several related approaches to the conservation of biological and ecological resources. These approaches arose in organizations with missions centered on the conservation of native biological diversity across both large and small landscapes. All such organizations face common challenges. They must manage for a wide diversity of species, natural communities, and ecological systems but cannot possibly develop management goals for each component of this diversity individually. They must manage in ways that allow natural ecological and evolutionary processes to play out, so that these landscapes remain ecologically dynamic rather than become stale ecological museums. And they must manage in ways that fully address impacts arising from human alterations to the landscapes, the surrounding regions, and the world – including effects ranging from invasive non-native species to air pollution and climate change. Additionally, these organizations rely on access to current scientific work and the cumulative knowledge of past investigations; and benefit from communication with each other. Such communication works best when the organizations can rely on a common vocabulary and shared set of tools, such as those offered by NatureServe and the Conservation Measures Partnership (http://www.conservationmeasures.org/CMP/).

The Ecological Integrity Assessment Framework addresses several crucial needs for conserving biological resources across natural landscapes:

- It provides a method for generating explicit, objective, scientifically based metrics and measurable outcomes for adaptive resource management.
- It provides a systematic, objective basis for identifying, quantifying and prioritizing the urgency of threats to biological resources.
- It provides a method for tracking the effectiveness of adaptive resource management actions.
- It permits objective comparisons among projects and within projects over time based on a common approach and vocabulary.
- It provides a consistent basis for clearly articulating research and monitoring needs in support of adaptive management.
- It links the conservation of landscape biodiversity to the conservation of ecological processes and resilience.
- It carries practical implications for organizing information, conducting analysis, and reporting results within the context of the NPS mission, GPRA and other reporting requirements.

Readers will quickly recognize some key challenges to implementing this science-informed framework. Knowledge of the biological and ecological resources of a given Park may be limited, including knowledge of their past and current status, ecological requirements and interactions, relationships to natural disturbances, and sensitivity to human-caused stresses. Limitations in scientific understanding may also hamper efforts to forecast how different species and systems will respond to climate change. Finally, Parks may lack the financial and technical resources to improve monitoring or promote research to address these gaps in knowledge. Fortunately, limitations in financial and technical resources need not pose a substantial challenge. NPS staff responsible for biological and ecological resources can rely on shared knowledge across the scientific and conservation community, to make the best use of existing data, concepts and models to support their efforts within each Park. In turn, by making explicit all key steps in the process of setting conservation goals and developing conservation plans, the Ecological Integrity Assessment Framework provides a foundation for making the best use of existing knowledge and adaptively improving goals and management practices as that knowledge improves.

Report Structure

This document is not intended as a User's Manual for the Ecological Integrity Assessment Framework. Rather, it aims to introduce the methodology to NPS scientists and managers and highlight its potential utility. The document begins with an overview of founding concepts in conservation science. The remainder of the document is organized around the three major steps in the framework: setting resources priorities (identifying what's important); assessing the status of priority resources (determining how it's doing); and setting management goals (stating desired outcomes). A concluding section suggests next steps toward a more complete exposition and demonstration of the Framework for the NPS. Additional reference material for this guide is found with the companion guide to Defining Meaningful Desired Conditions.

II. Founding Concepts

Traditionally, the establishment of parks and nature reserves has been driven by aesthetics and recreation; people love to visit spectacular places. The United States established the world's first national parks, Yellowstone and Yosemite, because of their scenic beauty and spiritual effect on visitors. The enabling legislation for the creation of Yellowstone states that the park is "… dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of the people." However, the enabling legislation also stipulated that the Secretary of the Interior "… shall provide against the wanton destruction of the fish and game found within said park and against their capture or destruction for the purposes of merchandise or profit."

This was a dramatic and important step in the 1870s when the nation's natural resources were still being wantonly over-exploited. However, the boundaries of these parks were drawn with no consideration of the needs of the plants and animals characteristic of these areas. This pattern of designating protected areas still holds true, by and large, today. Most national parks, national wildlife refuges, RNAs, ACECs, and private protected areas are designed based upon many considerations, with the needs of the biodiversity often having secondary importance. As a result, biological management is crucial to ensure the persistence of their characteristic plants and animals.

The publication of Rachel Carson's *Silent Spring* (Carson 1962) awakened the nation to the need to protect many of our plants and animals. The Endangered Species Act, signed by President Nixon in 1973, first codified the nation's commitment to biological conservation. Originally, the Endangered Species Act had an exclusive species-centric perspective. Recovery plans originally stipulated the number of populations and the size of each population necessary to ensure a species persistence. These plans stimulated population biologists to develop quantitative models that would begin to put bounds around their confidence in these recovery goals. This resulted in the development of many approaches to quantify and understand population dynamics, and especially to understand what constitutes a viable population.

Research on the concept of population viability led to many insights into the structure and functioning of natural populations. These insights included the recognition that many if not most populations are structured as meta-populations; populations of populations. In addition, it became clear that maintaining a population, or a meta-population, just above its viability threshold was not equivalent to maintaining ecologically functioning populations. For example, a population of 50 animals may be considered to be biologically viable, but inappropriately small to provide the ecological services – ecological roles – required of that species, be they pollination, seed dispersal, herbivory, predation, or disturbance.

These insights forced conservation planners to consider the necessity of protecting appropriate habitat that did not currently harbor populations of targeted species. The resulting expansion of research improved our understanding of what is necessary to protect a species. We now recognize that such protection must ensure that populations are sufficiently large to carry out their crucial ecological roles and sufficiently connected to allow for genetic and demographic interchange. In addition, many landscapes were found to harbor multiple endangered species, requiring conservation planning for the landscape as a whole rather than separately for each species. Together, these circumstances forced a reevaluation of what an effective recovery plan would be. As a result, Congress modified the Endangered Species Act in 1982 to require the preparation of overarching habitat conservation plans (HCP). The requirement for HCPs moved conservation planning away from a species-by-species approach, toward an emphasis on the conservation of significant habitats, ecosystems, and natural landscapes.

The most successful habitat conservation plans, for example the Coachella Valley, California HCP, integrate the needs of many threatened and endangered species with a landscape that includes both protected areas and private lands. Yet, even the best habitat conservation plans still focus on the relatively few threatened and endangered species, and thus may not address the needs of all the biodiversity within a given landscape.

Biodiversity and Landscape Ecology

The word "biodiversity," a combination of *biological* and *diversity*, has been used in so many situations that it's true meaning can be difficult to pin down. There are as many definitions as there are users. The term was probably first coined by W.G. Rosen in 1985. Rosen's original intent was to propose a word that captures the diversity of life, as a way to explicitly capture the idea that 'everything is linked to everything else'. Historically, geneticists communicated with geneticists, game managers communicated among themselves, and ecologists talked with their ilk. Coining the term 'biodiversity' was an attempt to pull them all together, making explicit the need to consider diversity at all biological scales when undertaking conservation planning.

This idea of habitat conservation planning that incorporates all biodiversity is not new. Aldo Leopold advocated this very idea over six decades ago:

> *The last word in ignorance is the man who says of an animal or plant: 'what good is it?'. If the land mechanism as a whole is good then every part is good whether we understand it or not. If the biota in the course of eons has built something we like but do not understand then who but a fool would discard seemingly useless parts. To keep every cog and wheel is the first precaution of intelligent tinkering. (Leopold 1953).*

However, merely designating land for protection does not equate to conserving the biodiversity residing on those lands. Effective conservation depends not just on persistence of the lands, waters, and physical landscape but also on the persistence of ecological processes that structure ecosystems and natural landscapes.

Additionally, beginning in the late 1970s, ecologists came to realize that their dominant "balance of nature" paradigm was flawed. This paradigm, exemplified in the writings of Clements (Clements 1916; Clements 1936), posits that every natural system develops an internal equilibrium in which the needs of all contributing species come into balance. Pickett and Thompson (Pickett 1978) proposed instead that natural systems are inherently dynamic and that repeated disturbance events are key to structuring ecosystems and maintaining biological diversity – a "dynamics of nature" paradigm. This concept dramatically changed our view of how the natural world works. We now understand that ecosystems are made up of patches of varying ages and that biological diversity results both from interactions among species and from patch dynamics driven by disturbance at many scales of space and time.

Building on this idea, many ecologists (e.g., Naveh 1984, Forman 1986, etc.) proposed that natural lands were comprised of hierarchies of patches; and that, depending upon the grain and extent of one's observations, you would see ever-changing mosaics of ecosystems within a natural landscape. These land mosaics define the spatial distribution of species, constraining and defining how they interact and carry out their life cycles. It seemed, therefore, that we could conserve biological diversity by conserving landscapes (or water-scapes) with habitat for all, and the disturbance regimes that ensure appropriate patch dynamics for each landscape.

However, ecologists quickly recognized a critical dilemma in this new understanding. When we develop plans for the conservation of any landscape, how can we possibly incorporate knowledge about, and actions directed toward, “all” of the landscape’s biodiversity? For example, just two beetle families dependent on deadwood for their existence (*Buprestidae* and *Cerambycidae*) contain about 50,000 species, roughly twice the global diversity of amphibians, reptiles, birds, and mammals combined (Hunter 1990). Clearly, one can never hope to plan for each species individually.

Ecologists have proposed several solutions to this dilemma. One focuses on the selection of a small suite of species to represent the full suite of biodiversity within a planning landscape. The second solution, emphasizing ecosystems, has been termed the “coarse filter/fine filter” approach.

The former strategy builds upon the concept of “umbrella” or “focal” species, whose requirements are believed to encapsulate the needs of all (or at least many) other species. This method identifies a set of species as proxies for different spatial and compositional attributes that must be present in a landscape to ensure persistence of both the focal species, and by association, other aspects of biodiversity (Lambeck 1997). It is believed that in planning for the most wide-ranging, and hence most habitat-area demanding species, a conservation plan built around a few, well selected focal species will sufficiently encompass requirements of all other species.

The strategy of using focal species has been tested in some circumstances (e.g., Carroll 2001) and widely criticized by a number of authors (e.g., Franklin 1993, Noss et al., 2002). In essence, these criticisms rest on the belief that because focal species are invariably large, wide-ranging, vertebrates they simply cannot be adequate proxies for the huge diversity of smaller animals as well as all plant species. The critics argue that the perceived grain and extent of physical and biological resources in any single landscape depend entirely upon the particular species present. As a result, vertebrates simply cannot serve as adequate proxies for insects, other invertebrates, or plant communities.

The alternative, “coarse filter/fine filter” approach was originally proposed by scientists from The Nature Conservancy (Jenkins 1976, Noss 1987) and focuses primarily on ecosystems, only secondarily on species. Coarse-filter focal ecological resources are identified first, and typically include all of the major ecosystem types within the planning landscape. Planners then consider whether individual species of concern, such as those that vulnerable, rare, or endangered, are adequately "captured" by the coarse filter. That is, the planners pose the question; If all major ecosystem types are conserved in sufficient area and landscape configuration, which of the key species will have sufficient habitat "swept along"? Those species that are not adequately addressed through ecosystem-scale conservation are included as additional foci for planning and conservation action – the "fine filter."

Planning for the persistence of ecosystems presents the same challenges as planning for the conservation of species; they both raise issues of spatial scale, patch dynamics (*sensu,* Pickett 1978), ecological connectivity, and the need to maintain a long-term perspective. Indeed, because ecosystems encompass entire assemblages of species populations, ecologists face the same challenges in planning for the persistence of ecosystems as they do in planning for the persistence of meta-populations.

Other Approaches to Conservation Planning

In addition to these two major approaches to planning for biodiversity – "focal species" and "coarse filter/fine filter" – conservation managers have also developed approaches are based on other environmental attributes and some commonly available data. These other approaches include planning for iconic species, abatement of perceived threats to resource values, ecosystem services (e.g., water quantity and quality, in addition to biodiversity), and index-based management. Table 1 summarizes these other common approaches.

Table 1. Other common approaches to planning for biological and ecological resource values

Approach	Description
Iconic Species	This approach focuses solely on individual species that are of great public interest and concern. Conservation planning focuses solely on the needs of these species to gain widespread public support. In many instances, benefits to these iconic species are apparent (e.g., successful species reintroductions). However, benefits from this approach to other aspects of biodiversity are not explicitly planned may occur only by coincidence. Lambeck (1997) proposed a biodiversity planning framework based on a suite of "focal species" that are selected to represent a diversity of spatial and compositional attributes within a landscape. He argued that, by carefully choosing these species, their figurative "umbrellas" would overlap sufficiently to ensure the conservation of all biodiversity within the landscape. This idea is the core of the Wildlife Conservation Society's Landscape Conservation Species planning model.

Table 1 (continued). Other common approaches to planning for biological and ecological resource values

Approach	Description
Threat Abatement	This approach focuses solely on perceived threats to resource values. For example, where land use, pollution, or invasive species are perceived as important threats to local resources, the planning process emphasizes mapping locations of these threats; then formulating strategies for their abatement. In many instances, especially in large, relatively intact landscapes, pervasive threats can be readily recognized and this provides an effective approach. However, in many other instances, insufficient attention to individual resource values can lead to unnecessary losses when less obvious threats go undetected. Most threat-based frameworks focus on the place, and not the biota. They originate by asking "what are the threats to this place" and then develop strategies to mitigate those threats. Prior to the development of the EIAF, presented in this document, The Nature Conservancy used such as threat-based framework. Over time, it became clear that this kind of approach begs the question of how much abatement is sufficient, the answer to which requires consideration of what the threats are threats "to."
Ecosystem Services	This approach typically involves identification of major services of widespread interest to local stakeholders (e.g., water quantity, soil stability, carbon capture). In many cases, conservation of major ecosystem services may provide substantial coincidental benefits to biodiversity. However, many species, communities, and mostly local ecosystem types can be easily ignored under this approach, because they do not provide a service to human populations, or their function is duplicated by a different, more common, ecosystem.
Index-based	This approach is most often driven by available data. One common example includes use of Natural Heritage ranks for known location of biodiversity (mainly rare species and communities). The combination of scores for relative Conservation Status (known as global rank and sub-nation rank), are combined with scores for the relative quality of each occurrence, to provide and overall "biodiversity significance" value for any portion of the landscape. This relative 'value surface' then provides an indication where conservation attention should be focused. While this approach can be quite effective at alerting planners to important location (e.g., to avoid in development projects), relatively little support is provided for management decision making. A second Index approach is based on indices of ecological structure. For example, the Benthic Index of Biological Integrity (B-IBI) looks at the food-web structure of aquatic invertebrate communities and relates these to system condition and resilience. Conservation assessments and priorities are based upon these index values. The IBI methodology arose specifically to help guide the management of water quality and its effects on stream ecosystems.

Ecological Integrity, Resistance and Resilience

The coarse filter/fine filter approach central to the EIAF recognizes the need to conserve biological diversity in part by conserving the natural disturbance regimes that contribute to the diversity of any given landscape. However, ecosystems everywhere today face disturbances of both unusual patterns and types as a result of climate change, the introductions of chemical pollutants and non-native species, among others. Consequently, management plans must also address the need to conserve both the “resistance” and “resilience” in ecosystems. Resistance refers to the capacity of ecosystems to tolerate disturbances without exhibiting significant change in structure and composition. Resilience, in turn, refers to the ability of a system to recover from disturbance, in the event that the disturbance exceeds the capacity of the system to resist changing at all (Holling 1973, De Leo and Levin 1997, Lindenmayer et al., 2008) . The central tenet of the EIAF is that ecosystems with greater ecological integrity, as defined here, will be more resistant and resilient to the effects of changing patterns and types of disturbance (Parrish, Braun et al. 2003). The second step of the Framework calls for the identification of ‘key ecological attributes’ that scientific understanding suggests will contribute significantly to focal ecological resource resistance and resilience. The EIAF then calls for building conservation management plans directly around the key ecological attributes identified for each such resource. Thus, unlike many other approaches, the EIAF explicitly addresses the need to conserve resistance and resilience in ecosystems in light of global change.

Sound Science in Conservation Planning

Regardless of the approach selected, all successful conservation plans share several key elements:

- There are clearly stated, mutually supportive conservation goals that drive the development of the plan. The goals communicate a compelling vision for the conservation and management of the planning area, park or landscape or resource.
- There are clear statements of desired conditions (DCs) generated from goals and include a description, metrics and measures of the resource. The DCs then drive the development of measurable program or project objectives. These objectives should translate the intention of the goals into measurable outcomes. The DCs, therefore, define what constitutes success. The objectives define what constitutes progress.
- Both goals and statements of desired conditions call for strategies that can be implemented within a reasonable period of time and within a reasonable budget. Effective goals and DCs are sufficiently clear that they can guide decisions about priorities, sequencing, and required investments in the actions needed to achieve progress and ultimate success.
- The plan explicitly identifies conservation strategies and objectives tied to each goal. Typical strategies are developed to abate the impacts of human activities or human caused changes on the landscape, or restoration or rehabilitation of areas incapable of natural recovery. Some strategies also identify actions to prevent threats to the focal conservation resources manifesting themselves.
- Each objective has a related monitoring assessment. Well written objectives point to measurable parameters and outcomes that can be used to monitor progress and document success. The monitoring assessment is set into place at the same time conservation actions or initiated.
- The most useful plans explicitly address the challenges of implementing conservation strategies at the appropriate scale. Too often, plans identify conservation strategies with no consideration of the potential, or cost, of implementation. For example, while mechanical thinning of forests can be used to manage fuel loads, implementation of this practice across several hundred thousand acres would likely involve insurmountable obstacles of cost and practicality. Successful

conservation plans recognize such challenges and propose activities that can be reasonably implemented.

- Plans are treated as living documents from the onset and are consistently modified and updated. Such plans explicitly document all challenges encountered by the planning team including: (1) gaps in the knowledge of the team, (2) assumptions that were made in during the planning process including assumptions about the biology or ecology of the focal ecological resources and (3) assumptions about biodiversity which is thought to be captured, through the use of these surrogate focal ecological resources. Living plans also identify additional information needs that could help improve the plan, change the priorities, or impact the conservation strategies.

III. Setting Resource Priorities (Identifying What's Important)

The establishing legislation, Foundation documents, and management and monitoring strategies for each Park often identify broad priorities for managing wildlife, vegetation, water resources and ecosystems. The Ecological Integrity Assessment Framework provides a method for converting these priorities into more specific goals based on a limited number of focal ecological resources in each Park. *Unless otherwise noted, species, communities and ecosystems will be referred to as ecological resources for the remainder of this document.*

Determining the focal ecological resources for a Park involves four tasks: (1) identifying the scope of the management effort; (2) identifying the suite of ecological resources of potential concern to the Park unit; (3) identifying stressors known, suspected, or anticipated to affect these resources; and (4) selecting a sub-set of the unit's ecological resources on which to focus planning and management.

Identifying the Scope

Geographic Scope

The resources and values present in a given Park or park management unit are many and varied. Regardless of the size and complexity of the area, it can be challenging to organize information for assessment and planning. Any given Park unit will contain a variety of ecological resources, such as streams, wetlands, or wildlife populations and their habitats. There may be physical resources, such as important geologic features or aquatic features. Natural resource values such as natural sounds and dark night skies are key links between the resources themselves and visitor experiences. There may also be cultural resources, such as important archeological sites, high-use recreational sites, or cultural landscapes, such as Civil War battle fields.

Effective resource planning begins with a clear and explicit identification of the scope of the planning effort. This includes determining the appropriate geographic area of interest and requires answering many questions. Given the size and complexity of an NPS unit, should one plan encompass the entire park and relevant surroundings? Might the plan for a large park be subdivided by landscape processes, major watersheds, habitat types, park management zones, and/or other geography? What are the specific resources and values of interest within that area? Is the ecological management plan part of a broad-based General Management Plan, or is it in response to a specific impact? What defining resources within the park require specific attention? Planning teams often follow an iterative process, through which they first define the geographic area of interest and then adjust that definition as focal ecological resources are identified. The goal of this process is to develop a clear understanding of the resources in need of assessment and the spaces where they occur.

Impact Analysis

In many cases, managers will not be able to refer to broad based analyses to respond to impacts. It is important, however, for the manager to consider the effective scope at which to respond to an impact. The scope at which impacts should be addressed can often be different from the level at which the impact is perceived. For example, plant invasions are perceived as a population and an immediate response might be to control or remove the specific occurrence. However, the manager may simply be treating a symptom and not a cause. By scoping resources at broader and finer levels than the perceived impact, the manager can assess whether she needs to address soil compaction and/or manipulate fire to facilitate outcomes of native plant communities. The manager can use this framework to identify the appropriate response scale by following steps to identify the key ecological attributes of a desired system.

Identifying Resources of Potential Concern

Once the scope is defined, the planning team needs to develop an overall sense of the biological diversity and related resources that a conservation plan must address. As discussed above (II, Founding Concepts), it is not possible to develop a plan that addresses every species and genetic stock, every natural community, and every ecological system present in a Park landscape. Some of these resources may not warrant individual conservation concern, because they are common and occur widely throughout the entire encompassing region. The rest, however, may comprise a vast list of biological resources of potential concern. Ultimately (see below), the planning team must identify a short list of focal ecological resources, the conservation of which will ensure, as a consequence, the conservation of all biological resources of concern. That is, the conservation of these focal ecological resources will create a "safety net" for the whole. Designing the safety net therefore requires some basic understanding of the whole.

Planners familiar with a Park unit may also have a sense of the stressors that threaten the biological diversity of the Park. For example, planners may perceive that high visitor use, air pollution, historic sites of chemical contamination, histories of fire suppression, or over-browsing from herbivores all pose threats to the ecosystem. This understanding of threats can provide an additional guide for identifying focal ecological resources, as described below. The present portion of the document addresses the need to identify the overall suite of biological and ecological resources of concern within a Park unit; biological inventories and vegetation classifications provide a useful start to this analysis.

Even characterizing the "overall suite" of biological resources for a Park unit begs the question of how to organize the resulting information, particularly for GPRA species and land health reporting, and for analysis of fundamental resources and values. A particularly useful approach to simplifying the process is to categorize the biological resources of the management unit into three levels of organization: *ecological systems, vulnerable species assemblages, and vulnerable species*. The planning team can map the distribution of the elements in each of these three categories, and work to ensure that the final list of focal ecological resources addresses conservation needs at all three levels. Table 2 summarizes these categories or levels of ecological resource values identified for an NPS unit.

Table 2. Summary of categories or levels of ecological resource values identified for an NPS unit.

System Type	Category	Number of Resources
Ecological Systems	Terrestrial ecosystems	10
	Freshwater ecosystems	2
Vulnerable Species Assemblages & Associated Habitats	Spawning fish assemblages	1
	Bat colony	1
	Migratory bird stopoever	1
Vulnerable Species	Vulnerable animal species	8
	Vulnerable plant species	12

This set of three categories establishes the 'coarse-filter/fine-filter' framework described earlier (II, Founding Concepts). The inclusion of ecological systems forces planning teams to consider the major ecological patterns and processes at work on the landscape, and also results in the inclusion of habitat for the more common and characteristic species. The ecological systems thus provide the 'coarse filter' for conservation planning. The lists of vulnerable species assemblages or individual vulnerable species then provide two practical 'fine filters' that capture crucial elements of biodiversity not otherwise represented in the list of ecological systems. Experience worldwide has shown this three-level approach to be both practical and effective (Groves 2003). It reduces complexity and costs associated with strict species-based approaches (e.g., Beissinger and Westphal 1988; Willis and Whittaker 2002) while allowing sufficient flexibility to integrate new information as technical hurdles are overcome (e.g., Fleishman et al., 2001; Carroll et al., 2001; Cushman et al., 2008).

The coarse-filter component of this approach requires standard classifications for terrestrial, freshwater and coastal marine ecosystems. Ecological classification, just like the systematic taxonomy of organisms, facilitates communication among scientists, planners, and managers. They form the basis for producing consistent maps, descriptions, and models of each ecological unit and the broader landscape where they occur. They also serve a critical role in *locating comparable sites* - within the management unit, or across the regional landscape – *to better understand natural variability* in ecological patterns and processes. In selecting or developing these classifications, one must address the conceptual and spatial scales of the resulting ecological units so that they will be most useful for management actions (e.g., mapping, characterizing dynamic processes, ecological monitoring). Once selected, these ecological units provide a practical framework to organize the landscape for assessment and for developing ecologically-based conceptual models. Classifications can be used to develop a tessellated arrangement of resources across a park, allowing for area-based condition reporting. Once resources are identified and mapped, integrity criteria can be developed or applied to those resources using this framework. For example, one might partition a large park landscape into terrestrial vs. aquatic ecosystem-based analyses, and/or segment the landscapes further along major environmental gradients, such as elevation-based life-zones (e.g., alpine ecosystems vs. montane forest and grassland vs. lowland shrubland and grassland). Each of these broader land and/or waterscapes then form the focus for conceptual ecological models to express assumptions about important natural dynamics such as disturbance processes, structural characteristics, and habitat attributes for species of interest.

Spatial pattern and ecological process are fundamentally entwined. Therefore, it can be useful to apply knowledge of characteristic spatial patterns among ecological units to help organize assessments. For example, Table 3 includes four categories commonly used to describe characteristic spatial pattern among terrestrial ecosystem and community type (Anderson et al., 1999). As the name implies, matrix-forming types tend to dominate a regional landscape. When viewed on a map, all other types tend to appear nested within these types. Where more than one matrix type characterizes a given park unit, chances are that your assessment should be segmented by these major types. Large patch types often occur nested within a larger matrix due to more local-scale disturbance patterns and/or environmental attributes. Small patch types most commonly define nested, specialized local environments, such as small wetlands or sparsely-vegetated rock outcroppings. Linear types, almost entirely occurring along coastal and riparian zones, organize a distinct set of ecological resources values. Attribution of ecological classification units by these basic types of spatial categories can be one useful step in organization of any ecological assessment.

Table 3. Spatial pattern descriptors for terrestrial ecosystem types

Spatial Pattern	Definition
Matrix	Communities or systems that form extensive and contiguous cover, occur on the most extensive landforms, and typically have wide ecological tolerances. Disturbance patches typically occupy a relatively small percentage (e.g., <5%) of the total occurrence. In undisturbed conditions, typical occurrences range in size from 2,000 to 100,000 ha.
Large Patch	Types that form large areas of interrupted cover and typically have narrower ranges of ecological tolerances than matrix types. Individual disturbance events tend to occupy patches that can encompass a large proportion of the overall occurrence (e.g.,>20%). In undisturbed conditions, typical occurrences range from 50-2,000 ha.
Small patch	Types that form small, discrete areas of vegetation cover typically limited in distribution by localized environmental features. In undisturbed conditions, typical occurrences range from 1-50 ha.
Linear	Types that occur as linear strips and are often ecotonal between terrestrial and freshwater ecosystems. In undisturbed conditions, typical occurrences range in linear distance from 0.5 to 100 km.

Similarly, aquatic ecosystems may lend themselves to categorization, such as lake vs. stream types, linear coastal marine habitats vs. extensive deep-water habitats, surface aquatic features vs. subterranean stream habitats, etc.

One cannot generally presume that by focusing solely on characteristic ecosystem or habitat types, the ecological requirements of all species will be adequately addressed. Some species that require focused attention may be addressed as members of predictable species assemblages (e.g., migratory bird stopovers, native fish assemblages, bat hibernacula, etc.). Other species require individual attention as ecological resources in their own right. Examples of such species include those known to be rare or imperiled, declining, narrowly endemic to the park and surroundings, of widely disjunct distribution, as well as migratory species with specific vulnerabilities to habitat fragmentation. Still, other species should be addressed individually because they play critical ecological roles (such as connecting food webs; or as triggers to characteristic disturbance processes). As one example, beavers are commonly cited as 'keystone' species due to the cascading effects of their dam-building activity. Treatment of these assemblages and species as individuals reflects the "fine-filter" approach to address natural diversity that could otherwise "slip through the cracks" in ecological assessments.

But here again, it is important to consider spatial characteristics of these biological resources. Individuals of a given species of plant, insect, or amphibian might live out their entire life cycle within the confines of a very small habitat patch, while larger-bodied animals utilize much more extensive areas. Larger still, migratory species, be they migratory mammals, herpetofauna, fish, or birds may require consideration of vast inter-connected lands and waters to complete their life cycle. Selecting resources for assessment must explicitly consider these spatial dimensions. Most commonly, local scale species are represented by those that have been already highlighted as rare or imperiled. Critical keystone species may often reflect intermediate scales in their habitat requirements. Large-bodied and/or migratory species may not fall into either of these previous categories, but are seen to be vulnerable to large-scale habitat fragmentation.

By representing multiple scales of ecological organization *and* geographic scale of occurrence, we hoped to represent efficiently the ecological processes that support all native biological diversity. Table 2 provides an example where this approach was applied to a specific NPS unit.

This initial listing provides a useful starting point for analysis, but time may lead to additions or deletions. Through the course of a given assessment process, one might recognize some redundancy among some species habitat requirements, leading to effective streamlining. But at the outset of an analysis, these redundancies may not be apparent, so application of screening criteria to define a robust 'fine-filter' is a critical step.

As previously mentioned, there may be other types of resources that are important for analysis. Even among ecological resources, there can be resources that have been modified historically, and that modified state is important to conserve. This is commonly the case with historical parks, where the human-altered landscape depicting conditions from American history are central to park management. In these cases, the site is characterized by some form of 'semi-natural' or 'cultural' vegetation; the former being vegetation that, while perhaps defined with species native to the region, have no clear 'natural' analog and are clearly the result of past intensive human manipulation. These types of resources can most certainly be integrated into this assessment framework. They just need to be clearly described.

Identifying Relevant Stressors

We noted above that planners familiar with a Park unit may also have a sense of the stressors that threaten the biological diversity of the Park. This understanding of known and suspected threats can provide an additional guide for identifying focal ecological resources. The planning team must select focal ecological resources that collectively are vulnerable to the full range of leading threats to the Park's biological resources overall. Conservation planning for the focal ecological resources will then establish goals for the abatement of critical threats that will benefit the entire spectrum of biological resources in the planning unit.

Management plans for each Park will contain information on known and anticipated threats to the Park's defining resources. While this information provides an important starting place, it may not reflect a systematic consideration of the threats faced by the ecological systems, vulnerable species assemblages, and individual vulnerable species present across the Park. In this case, the planning team will need to consider a wider array of potential threats to help guide the selection of focal biological resources for conservation.

Organizations such as the International Union for Conservation of Nature (IUCN) and the Conservation Measures Partnership (CMP) have developed taxonomies of the threats faced by biodiversity around the world, from local to landscape and regional scales The IUCN-CMP classification can be found at http://www.iucn.org/about/work/programmes/species/red_list/resources/technical_documents/new%20classification_schemes/index.cfm. Table 4 lists the eleven Level-1 classes of threats identified in the IUCN-CMP classification; the classification also offers finer-level categories under each of these eleven, to help planning teams more precisely identify threats in any given landscape.

Table 4. IUCN-CMP Classification of Direct Threats

Level-1 Class	Explanation
1. Residential & Commercial Development	Threats from human settlements or other non-agricultural land uses with a substantial footprint tied to a defined and relatively compact area, unlike 4. Transportation & Service Corridors or 6. Human Intrusions & Disturbance.
2. Agriculture & Aquaculture	Threats from farming and ranching as a result of agricultural expansion and intensification, including silviculture, mariculture and aquaculture. Threats resulting from the use of agrochemicals, rather than the direct conversion of land to agricultural use are classified under 9. Pollution.
3. Energy Production & Mining	Threats from production of non-biological resources; does not include water use, which falls under 7. Natural System Modification.
4. Transportation & Service Corridors	Threats from long narrow transport corridors and the vehicles that use them. These corridors create fragmentation of habitats and lead to other threats including farms, invasive species, and poachers.
5. Biological Resource Use	Threats from consumptive use of wild biological resources. Consumptive use means that the resource is removed from the system or destroyed. Threats in the class can affect both target species (harvest of desired trees or fish species) as well as "collateral damage" to non-target species (trees damaged by felling or fisheries bycatch) and habitats (coral reefs destroyed by trawling). Includes species persecution/control.
6. Human Intrusions & Disturbance	Threats from human activities associated with non-consumptive uses of biological resources that alter, destroy and disturb habitats and species. Non-consumptive use means that the resource is not removed. These threats typically do not permanently destroy habitat except in the extreme.

Table 4 (continued). IUCN-CMP Classification of Direct Threats

Level-1 Class	Explanation
7. Natural System Modification	Threats from actions that convert or degrade habitat in service of "managing" natural systems, often to improve human welfare. This category deals primarily with changes to natural processes such as fire, hydrology, and sedimentation, rather than land use. It does not include threats relating to agriculture (see 2. Agriculture & Aquaculture), or infrastructure (see 1. Residential & Commercial Development and 4. Transportation & Service Corridors).
8. Invasive & Other Problematic Species & Genes	Threats from non-native and native plants, animals, pathogens/microbes, or genetic materials that have or are predicted to have harmful effects on biodiversity following their introduction, spread and/or increase in abundance.
9. Pollution	Threats from introduction of exotic and/or excess materials or energy introduced to the environment from point and nonpoint sources. Pollutants may be identified simply as "Pollution" or as effluent from another, more specific threat class if known.
10. Geologic Events	Strictly speaking, geological events may be part of natural disturbance regimes in many ecosystems but should be considered when other stressors have left a biological resource more vulnerable to the disturbance.
11. Climate Change & Severe Weather	Threats from long-term climatic changes which may be linked to global warming and other severe climatic/weather events that are outside of the natural range of variation. Some climatic events may be part of natural disturbance regimes, but even then should be considered when other stressors have left a biological resource more vulnerable to the disturbance.

Park planning teams can use systems of categorization such as the IUCN-CMP classification to systematically identify the most critical threats facing each of the ecological systems, vulnerable species assemblages, and individual vulnerable species identified for a Park unit. Such threats can include legacy effects of past human activities in and around the Park, the effects of ongoing human activities, and potential effects from anticipated new or expanded stressors. Planning teams can then identify which threats affect the greatest number of biological resources across a Park unit, which biological resources are most vulnerable to the greatest number of threats, and which threats affect only limited but nevertheless potentially important resources or affect resources in only limited geographic portions of the Park landscape.

Settling on Focal Resources and Planning Landscapes

Planning teams face a number of challenges when trying to winnow the list of potential focal ecological resources to a final, manageable set. Commonly, teams avoid making difficult decisions by creating lists of twenty or more "focal" or "crucial" ecological resources. Unfortunately, the identification of too many focal ecological resources confounds the planning process and brings it to a halt. Discussions often descend into arguments about conflicting goals in marginal differences among candidate focal ecological resources, when these differences have only secondary importance.

Similarly, identifying *too few* focal ecological resources results in a different suite of challenges that are no less significant. Upon recognizing that one cannot plan for conservation of dozens of species, natural communities and ecosystems simultaneously, teams often swing to the opposite extreme.

Typically, they identify a very small number of focal ecological resources by selecting resources that are so poorly defined and diffuse as to be unmanageable for planning. For example, a planning team might recognize it is impossible to plan for each of the dozens of native fish species and so choose to define the “native fish assemblage” as a single, all-encompassing focal ecological resource. Because of the wide diversity of habitat requirements among native fish species, this aggregation provides little help in developing effective conservation strategies.

The coarse filter / fine filter approach allows planning teams to winnow the number of planning targets to an effective, reasonably sized suite of focal resources through a logical and rigorous process. Planning teams should apply the above mentioned criteria to identify **fewer than a dozen** focal ecological resources for planning purposes.

Planning teams should guide their efforts to identify a final suite of focal ecological resources using these criteria:

1) Do the selected resources, in total, adequately represent the important biodiversity within the park?
2) Do the selected resources adequately represent or provide for the conservation of all key species identified within a Park's master plan? Such species may include rare, threatened, and endangered species as well as those iconic species that have been identified to be important to achieving the overall mission of the Park.
3) Will the selection of these focal ecological resources lead to actions that will adequately address threats affecting all other biological and ecological resources in the Park?

If the planning team cannot reasonably settle on any collection of 12 or fewer focal ecological resources using these criteria, it likely indicates that the complexity of the planning circumstance warrants some form of geographic subdivision. Small NPS units may lend themselves to one application of the EIAF framework, whereas large and complex units will likely require subdivision and iteration to effectively apply the framework (see comments above on geographic scope).

IV. ASSESSING THE STATUS OF FOCAL ECOLOGICAL RESOURCES (Determining How Focal Ecological Resources Are Doing)

The assessment of each focal ecological resource involves four tasks: (1) identifying the "key ecological attributes" for each focal resource; (2) identifying monitoring indicators for each key attribute; (3) estimating an ecologically acceptable range of variation for each indicator and thresholds of unacceptable change; and (4) assessing the status of each focal resource based on indicator data using a standard "scorecard" methodology.

Identifying Key Ecological Attributes

When we look at undisturbed examples, or occurrences, of a species, biological community or ecological system, we see that these share two types of characteristics. First and foremost, we see that the occurrences exhibit similar characteristics of biological structure and composition. For example, undisturbed populations of a particular marine mammal will be similar in their age structure and sex composition and health-related stresses, within some measurable range of variation. Second, we see that the occurrences exhibit similar ecological processes, and occur in settings with similar environmental regimes and constraints that play particularly important roles in distinguishing, sustaining or limiting the resource. For example, every riverine system has a characteristic hydrologic regime, i.e., a distinct pattern of short and long term low flows, high flows, and floods. Different river systems have natural hydrologic regimes with different characteristics, and these characteristics may be crucial to the life cycles of species native to the channels, riparian zones, and floodplains of each river system. Changes in the characteristics of a river system's hydrologic regime will trigger changes in the entire aquatic community, and hydrologic changes beyond the range historically experienced by the ecosystem will likely result in significant shifts in the biota.

The literature of ecology calls such important characteristics of biology, ecology and physical environment, "key factors," "dominant characteristics and drivers," "structuring variables," or "key ecological attributes." The EIAF uses the latter term, and defines it as follows:

> *A key ecological attribute of a focal ecological resource is a characteristic of the resource's biology, ecology, or physical environment that is so critical to the resource's persistence, in the face of both natural and human-caused disturbance, that its alteration beyond some critical range of variation will lead to the degradation or loss of the resource within decades or less.*

Key ecological attributes of a resource include:

- Critical or dominant characteristics of the resource, such as specific characteristics of: (a) demographic or taxonomic composition; (b) functional composition; (c) spatial structure; (d) range or extent; and
- Critical biological and ecological processes and characteristics of the environment that: (a) limit the regional or local spatial distribution of the resource; (b) exert pivotal causal influence on

other characteristics; (c) drive temporal variation in the resource's structure, composition, and distribution; (d) contribute significantly to the ability of the resource to resist change in the face of environmental disturbances or to recover following a disturbance; or (e) determine the sensitivity of the resource to human impacts.

As noted earlier, conservation of such characteristics and processes will contribute not only to current ecological integrity but to the resilience of species populations, natural communities, and ecological systems in the face of climate change and other global causes of stress.

Conservation planners conventionally use three broad headings to help identify key ecological attributes: Size, Condition, and Landscape Context. These three "Summary Integrity Factors" partially overlap, and provide starting points for identifying potential attributes to consider.

- "*Size*" refers to attributes related to the numerical size and/or geographic extent of the focal ecological resource. Examples include the size of a population of a species, the number of viable sub-populations, or the area within which a particular ecological system occurs.
- "*Condition*" refers to attributes related to biological composition, reproduction and health, and succession; critical ecological processes affecting biological structure, composition and interactions; and physical environmental features and dynamics within the geographic scope of the focal ecological resource. Examples include species composition and variation, and patch and succession dynamics in ecological systems, and locally generated disturbance regimes that trigger these dynamics.
- "*Landscape Context*" refers both to the spatial structure (spatial patterning and connectivity) of the landscape within which the focal ecological resource occurs; and to critical processes and environmental features that affect the focal ecological resource from beyond its immediate geographic scope. Examples of the former include attributes of fragmentation, patchiness, and proximity or connectivity among habitats. Examples of the latter include connectivity between, and movements of matter and energy between a focal ecological system and surrounding systems; and regional or larger-scale disturbances.

Identifying the key ecological attributes for a focal ecological resource involves building a *conceptual ecological model*. This model must rest on knowledge of the resource itself, its setting, and similar or associated species, natural communities or ecological systems. The result is a set of hypotheses about how the focal ecological resource "works," its defining characteristics and dynamics, and critical environmental conditions and disturbance regimes that may act as drivers of these characteristics and dynamics. These hypotheses both guide management and monitoring, and highlight gaps in knowledge that require additional investigations.

The identification of key ecological attributes for each focal resource is an iterative process. However, there is no rule for the "best" number of key ecological attributes to identify. An overly long list will result in an overly complicated model with which to guide management and monitoring. Conversely, an overly short list could miss something crucial. Instead, the final list should focus attention on those potential key ecological attributes that are the *most defining, most critical or pivotal* to the persistence of the focal ecological resource and its natural internal dynamics, and that *most directly* affect the resource. If an attribute cannot be easily integrated into a conceptual, or quantitative, model it is a signal that it is not critical to ensuring the persistence of the focal resource.

The knowledge to inform this process comes from experts, and from scientific publications or records in conservation databases that provide information on key ecological attributes. Examples of such databases include those from the NPS Natural Resource Program Center, NatureServe and the Heritage Network (http://www.natureserve.org/getData/eia_integrity_reports.jsp), and the IUCN (www.iucn.org). Other focal ecological resources may be less well documented but still known to experts, including people with expert traditional knowledge. The knowledge brought to bear may include knowledge of the particular type of focal ecological resource not only within the immediate landscape of interest but throughout its range of occurrence; knowledge of other, similar types of species, communities or ecological systems; knowledge derived from ecological models; and general ecological principles.

Recognized threats to an ecological resource also provide crucial information for the identification of key ecological attributes. Threats to a focal ecological resource are human activities, structures, or institutions – or consequences of these – that could cause or have caused stress to the resource. Such stress must necessarily involve the alteration of one or several key ecological attributes beyond their acceptable ranges of variation. Consequently, knowledge of how specific human actions cause harm to a focal ecological resource can provide insight into the resource's key ecological attributes, and *vice versa*.

However, key ecological attributes do not simply consist of those characteristics of a focal ecological resource that are threatened by human interference, nor do they consist solely of those characteristics that are thought to be amenable to direct conservation management. Rather, key ecological attributes provide a picture of how the resource *should* be and how it *should* function in the absence of obvious human intrusion (e.g., Native American use of fire in certain landscapes augmented lightening-set fires, while in other circumstances, any human-set fire was a natural aberration). They direct attention to those critical aspects of a resource that are impaired and require restoration, *and* to those that currently lie within their acceptable ranges and need to be kept there. Tables 5 and 6 provide examples of the types of key ecological attributes frequently identified for terrestrial (e.g., forest, shrubland, grassland, wetland) and riverine ecological systems.

Table 5. Common types of key ecological attributes for terrestrial ecological systems.

Terrestrial Attribute Category	Key Attributes
Environmental Disturbance Regimes	Fire area/intensity regime
	Wind disturbance regime
	Precipitation & flooding extremes
	Air temperature extremes
	Geologic disturbances
	Air quality, cloudiness

Table 5 (continued). Common types of key ecological attributes for terrestrial ecological systems.

Terrestrial Attribute Category	Key Attributes
Connectivity	Connectivity with adjacent systems (terrestrial, aquatic)
	Connectivity among similar & different patch types within target system
Hydrology	Precipitation (rain, snow, fog)
	Soil moisture
	Surface water - groundwater exchange
	Snow/ice cover
	Freeze/thaw
Soils Chemistry & Structure	Soil chemistry (organic content, nutrients, other chemicals, gases, salinity)
	Soil temperature & pH
	Soil structure & drainage
	Soil erosion & deposition
Biotic Interactions, Composition, Structure	Keystone species and/or functional groups
	Rare/sensitive species or species groups
	Food web structure (guilds)
	Component communities & seral stages
	Spatial arrangement of key species & communities
	Migration-aggregation-dispersion
	Vegetation stratification & structure within patches
	Infestations & mass grazing
	Seed bank dynamics

Table 6. Common types of key ecological attributes for riverine ecological systems.

Terrestrial Attribute Category	Key Attributes
Channel Morphology & Sediments	Channel erosion-deposition, stability-instability
	Channel shape, macrohabitat sequencing Bed/bank porosity & texture
	Bed/bank sediment chemistry
	Coarse organic matter
Connectivity	Drainage/flow-path connectivity
	Flood-zone inundation-recession connectivity
	Surface-groundwater connectivity
	Riparian corridor continuity
	Riparian corridor-upland connectivity

Table 6 (continued). Common types of key ecological attributes for riverine ecological systems.

Terrestrial Attribute Category	Key Attributes
Hydrology	Surface water flow regime
	Surface water elevation
	Surface/groundwater exchange
	Ice cover & transport
	Spatial extent of disturbances
Hydrochemistry	Water chemistry (ions, compounds, gases, salinity)
	Water temperature & pH
	Particulate & dissolved organic matter
	Water turbidity/clarity
	Plant litter & mineral inputs
	Solar and geothermal inputs
Biotic Interactions, Composition, Structure	Keystone species and/or functional groups
	Rare/sensitive species or species groups
	Food web structure (guilds)
	Component communities & seral stages
	Spatial arrangement of key species & communities
	Migration-aggregation-dispersion
	Infestations & mass grazing

Two questions often arise in discussions of key ecological attributes. First, why is it necessary to work with them at all? That is, why is it not better to set goals more holistically, e.g., for "a healthy elk population" or "a healthy stream community"? Such holistic goals may have a certain appeal for communicating priorities or intentions. However, without information on individual key attributes (which in turn should inform decisions about desired conditions, see below), resource managers must act without objective guidance on what, precisely, needs to be managed in order to achieve any such more holistic goals. That is, without objective and rigorous criteria that define what "healthy" means, such holistic goals provide no guidance for resource management. Additionally, holistic goals provide managers with no way of knowing if their work has been effective. Key ecological attributes identify those specific characteristics that require individual attention, for a manager to successfully conserve a resource. They also provide quantifiable measures, with which to track progress toward those goals. Key ecological attributes can also be compared among resources, and identified consistently for entire types of resources that may occur across many landscapes. They thus provide a common framework for using and building knowledge. Key ecological attributes provide managers with a common, objective currency for discussing and guiding conservation and land management.

Second, why is it necessary to include two broad kinds of variables in a list of key ecological attributes – both the crucial biological characteristics of the resource, and the processes and environmental characteristics that shape these key biological attributes? It would seem that, if all crucial biological characteristics of a resource lie within their ecologically appropriate ranges, then the crucial drivers of this variation must also lie within their own appropriate ranges. However, a complete list of the key ecological attributes for a resource should include both kinds, for two reasons. First, a central purpose of the EIAF methodology is to identify those aspects of the ecology of a resource that could be affected by human activities or changes in the surrounding environment. Doing so will help guide the assessment of threats and the development of conservation management strategies. This usually requires identifying the critical ecological processes and environmental characteristics that shape the resource. Conserving such critical ecological processes and environmental characteristics additionally will support the resilience of each focal resource in the face of global change. Second, biological effects often lag behind changes in larger processes and environmental conditions that cause these effects. For example, the species composition of a montane wetland may take years to change following a change in its hydrology. Including both broad kinds of variables in the list of key ecological attributes for a resource provides a means for identifying cause-effect relationships. Managers must understand such relationships in order to develop effective long-term management plans. This becomes increasingly relevant in applying concepts of ecological resiliency to conservation planning in the face of global climate change. Key ecological attributes may act as “fast” and “slow” drivers of the resource in question; both must be conserved.

Slow drivers are attributes that remain relatively constant over time despite inter-annual variation in weather, grazing, and other factors, because they are buffered by stabilizing feedbacks that prevent rapid change (Chapin et al., 1996). Critical slow variables include presence of particular functional types of plants and animals (e.g., evergreen trees or herbivorous mammals); disturbance regime and the capacity of soils or sediments to supply water and nutrients. Slow variables in ecosystems, in turn, govern fast variables at the same spatial scale (e.g., deer or aphid density, individual fire events) that respond sensitively to daily, seasonal, and inter-annual variation in weather and other factors (Chapin et al., 2008).

Identifying Indicators

Managers cannot assess the actual status of a resource’s key ecological attributes without considering how to measure them, i.e., what indicators to use. Once you identify practical, measurable indicators for each key ecological attribute, you can develop a program to monitor the status of your resources and the effectiveness of your management actions.

An indicator, in simplest terms, is what you measure to keep track of the status of a key ecological attribute. An indicator may be either:

- A specific, measurable characteristic of the key ecological attribute, such as the total number of adults in a population;
- A collection of such characteristics combined into a “multi-metric” index, such as a multi-species index of forest canopy composition; or
- A measurable effect of the key ecological attribute, such as a ratio of the frequencies of two common taxa of aquatic insects (the indicator) that varies with changes in average nitrate concentration (the key attribute) in a stream.

Indicators are selected to meet eight criteria (Noss 1990). Indicators must be:

1) Specific: unambiguously associated with the key ecological attribute of concern and not significantly affected by other factors.
2) Measurable: measurable by some procedure that produces reliable, repeatable, accurate information.
3) Sensitive: able to detect changes that matter to the persistence of the focal ecological resource (see discussion of thresholds and acceptable ranges of variation, below).
4) Comprehensive: able to detect changes across the entire potential range of variation in the key ecological attribute, from best to worst condition.
5) Timely: able to detect change in the key ecological attribute quickly enough that project managers can make timely decisions on conservation actions.
6) Technically feasible: amenable to implementation with existing technologies without great conceptual or technological innovation.
7) Cost-effective: able to provide more or better information per unit cost than the alternatives.
8) Partner-based: compatible with the practices of key partner institutions in the conservation effort, or based on measurements they can or already do collect.

It is rarely possible to identify a single indicator that meets all eight criteria for an individual key ecological attribute, particularly the first six, scientific criteria. In such cases, managers must use several indicators together to obtain a more reliable or more complete picture of what is going on. For example, field surveys and analyses of aerial photographs together may provide complementary information on forest tree composition that is more accurate and reliable than either indicator on its own. Table 7 provides examples of key ecological attributes and their potential indicators for a hypothetical riparian forest community.

Table 7. Example of indicator selection for the key ecological attributes of a hypothetical riparian forest community

Summary Integrity Factor	Key Ecological Attribute	Indicator
Landscape Context	Landscape Composition	Edge ratio of natural/non-natural habitat (buffer)
	Landscape Structure	Distance to upstream and downstream artificial breaks in community distribution
	Landscape Structure	Within-community fragmentation index
	Landscape Structure	Lateral distance to nearest road, other infrastructure, or anthropogenic land cover
Condition	Community Structure	Canopy structure index
	Community Structure	Mean canopy age
	Community Composition	Percent cover of native plant species
	Community Composition	Presence of exotic plants or weedy natives

Table 7 (continued). Example of indicator selection for the key ecological attributes of a hypothetical riparian forest community

Summary Integrity Factor	Key Ecological Attribute	Indicator
Condition (continued)	Hydrology	River hydrologic regime integrity (index)
	Hydrology	Water table depth regime integrity (index)
Size	Area	Size relative to other occurrences
	Area	Size proportional to historic extent of patch

Planning teams must consider three broad categories of indicators, representing three levels of intensity in data collection (Brooks et al., 2004; Tiner 2004; EPA 2006): (1) Remote Assessment, (2) Rapid Assessment, and (3) Intensive Assessment.

- Remote-Assessment indicators rely primarily on remotely sensed information. These indicators may require field calibration and vary in their spatial resolution as well as in their applicability for different places and dates and in the cost of procuring the data.
- Rapid-Assessment indicators typically involve combinations of information from remote sensing and qualitative field assessments. Expert field judgment may play a strong role in this level of assessment, for example in the use of field-based visual assessment methods (Fennessy et al., 2004).
- Intensive-Assessment indicators typically require field-based assessments or sample collection, often include quantifiable field measurement, and may include laboratory measurement of samples returned from the field. Considerations of field sample design matter the most with intensive-assessment indicators.

Remote-assessments are often limited by the availability of imagery, and by the season of acquisition. These data are, however, extensive and capture an entire planning area or park. Rapid and Intensive methods vary in their costs and accuracy and will often provide data on only limited numbers of locations or specific monitoring dates. In general, the greater the need to monitor a particular key ecological attribute to guide management, the greater the need will be to use the more focused data-intensive types of indicators. That is, Remote or Rapid assessment indicators may be sufficient for many purposes, but some management purposes will require the use of Intensive assessment indicators as well. Ultimately, however, the choice of which level of indicator to use for each type of key ecological attribute will depend on the need to meet the eight criteria listed above. For example, in some cases remote assessment can meet all eight criteria and thereby satisfy all management needs for a given key attribute. Table 8 summarizes the potential uses of these three levels of indicators in the Ecological Integrity Assessment Framework. A general rule-of-thumb is to identify those indicators that provides sufficient information most economically. A single, costly indicator may provide more precise, but poorer quality information than a suite of qualitative assessments.

Table 8. Indicator levels in ecological integrity assessments.

Indicator Level	Remote-Assessment Indicators	Rapid-Assessment Indicators	Intensive-Assessment Indicators
Purpose	• Indicate status of key ecological attributes for a focal ecological resource usually at larger spatial scales and/or at coarser spatial resolution	• Indicate status of key ecological attributes for a focal ecological resource at intermediate to fine spatial scales or spatial resolution; multiple measurement locations can provide wide spatial coverage	• Indicate status of key ecological attributes for a focal ecological resource at fine spatial scales or spatial resolution; multiple measurement locations can provide wide spatial coverage
Data Sources	• GIS and remote-sensing metrics for landscape or waterscape conditions within polygon(s) with limited ground-truthing • GIS and remote-sensing metrics for landscape or waterscape conditions across areas surrounding the polygon(s) of interest with limited ground-truthing	• Relatively simple field-based metrics including visual, auditory and rapid bioassessment methods, and data from portable field-monitoring instruments • Remote sensing metrics with limited to intense ground-truthing • Fixed field instruments with data logging at long-term monitoring stations	• Simple to complex field-based metrics, often quantitative, collected within a statistically appropriate sampling design • Laboratory analyses of field samples collected within a statistically appropriate sampling design
Examples	• Landscape Development Index (integrates a series of land use categories) • Landscape mosaic composition and pattern • Land cover fragmentation • Road, dam, or navigation channel density • Impervious surface density • Vegetation density	• Habitat patch connectivity • Vegetation structure (qualitative) • Plant species (including exotic spp.) relative density or dominance • Stream channel habitat quality • Forest bird community composition • Hydrologic or water clarity regime • Fire history (from historic records)	• Vegetation structure (quantitative) • Plant species (including exotic spp.) absolute density or dominance • Animal species (including exotic spp.) presence/absence, density • Water or soil chemistry parameters • Organism health measures

Estimating Acceptable Ranges of Variation

Species, natural communities, and ecological systems all evolve within dynamic environments; and naturally exhibit some range of variation in their attributes over time and space. For example, the age and species composition of any forest canopy naturally vary over time and from one stand to the next; and any forest naturally experiences varying frequencies and intensities of disturbance from fire, drought, wind damage, or flooding. Similarly, reef fish populations naturally vary over time and from one part of a coastal zone to another; and coastal areas naturally experience varying frequencies and intensities of nutrient and sediment inputs, tides, wave action, and storms. The resulting natural variation is not random. Instead, it occurs within some range determined by the physical environment (e.g., geology, climate) and the interactions among species. Within the limits of this range, further, the variation may be either patterned (e.g., cyclical) or random; and may play out over scales of time from hours and days to decades and centuries.

This natural variation in the physical environment and in the interactions among species creates a dynamic "template" that determines which species from the regional pool of species may (or may not) persist in a given area. This template is the stage on which species evolve. The natural variation in this template is thus essential to maintaining biodiversity.[1] We use one or more key ecological attributes to describe this template for each resource value, and recognize the natural variation in each key ecological attribute as a crucial feature of the template. The Ecological Integrity Assessment Framework directly incorporates knowledge of natural ranges of variation and its ecological importance into the setting of management goals for focal ecological resources.

Acceptable versus Natural Ranges of Variation

Resource managers often use the concept of a natural range of variation, or overall natural variability. However, what is 'natural' can be difficult to define, given limited knowledge of ecosystems, the extent of past human activity, and the likely effects of ongoing and future climate change. Scientific knowledge of most ecosystems has a relatively short history, as does the preserved record of most environmental regimes (fires, floods, etc.). The variation in ecological dynamics that we observe within years or decades can be part of much larger trends or cycles spanning centuries or millennia. Indeed, it is important to recognize that no ecosystem, natural community, or species is ever static when viewed on such larger scales of time.

Human activity also has thoroughly transformed many places throughout the world, and no place is free of human impacts (Hunter 1996). Much as a changing climate throughout the Holocene (past 12,000 years) brought about changes in many of aspects of ecosystems, and resulted in many patterns of species composition we see today, so too have certain human activities shaped ecosystems. Humans have brought about large-scale and long-term changes in ecosystems even far from our

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[1] Conservation resource values evolve as a result of long-term environmental change and the processes of natural selection acting on species and their interactions. Consequently, the natural range of variation for one or more key ecological attributes will also change over the long term. For purposes of conservation planning with a horizon of 50 to 100 years, we normally treat the natural variation in each key attribute as occurring within stable limits. However, there may be situations in which this is not appropriate.

farms and cities, for example through hunting and selective tree removal, releasing non-native species, setting fires, and diverting streams. In many instances where the rate and magnitude of human-induced change may be limited, we can safely subsume their effects within a practical 'natural' range of variation. That is, we can assume that their effects have had only a limited impact on the evolutionary environment of biodiversity. However, often we *can* detect human effects causing rapid and substantial ecological change. And we can do so not only in recent, better documented times but in the more distant past, for example from records of ancient land clearing for corn production, desert stream diversions, or the draining of arable swamplands. When we can detect such more significant human effects, we need to presume them to be outside of some practical, ecologically functional range of variation (i.e., likely resulting in local extinctions and other biodiversity impacts).

Global climate change is bringing about changes in regional and local climate. Every place on Earth now faces changes in the magnitude, timing, frequency, and duration of atmosphere-driven conditions – from changes in seasonal temperatures and weather patterns to changes in the temperature and pH of our oceans – many potentially outside the range of historic variation. The ecosystems of tomorrow in every region potentially will experience ranges of variation in atmosphere-driven conditions far different than have the ecosystems in these regions even in the recent past.

Given these challenges, some argue that the concept of "natural range of variation" has no practical utility for the management of biological resources. However, these critics tend to overlook the central importance of this concept to managing natural systems, and the ways it can be appropriately applied. First, it is the *knowledge* of natural variation that informs our goals and evaluations of current conditions, but this knowledge does not *a priori* constrain how we state desired conditions (see next section). Second, if resource managers do not apply this knowledge, they by necessity assume the task of *engineering* or *micro-managing* all aspects of ecosystem composition, structure, and dynamic process. There are few instances (beyond intensive agriculture and urban ecosystems) where anyone is adequately equipped to take on this role.

The Ecological Integrity Assessment Framework addresses these concerns about natural ranges of variation through its definition of "key ecological attributes" and the need to focus on merely *acceptable* ranges of variation. As noted above, we define key ecological attributes as characteristics of a resource's biology, ecology, or physical environment that are so critical to the resource's persistence, in the face of both natural and human-caused disturbance, that their alterations *beyond critical ranges of variation* will lead to the degradation or loss of the resource within decades or less. Our estimates of these critical, acceptable ranges of variation serve as crucial, practical hypotheses to guide the management *process*. They will (indeed, must) evolve as our knowledge grows over time.

Thresholds in Acceptable Ranges of Variation

The Ecological Integrity Assessment Framework posits that *critical thresholds* exist in the range of potential variation for each key ecological attribute, for each focal ecological resource. These are thresholds, outside of which managers should anticipate – or sometimes may already observe – signs of unacceptable change or degradation to the resource of concern.

Such unacceptable alteration for species populations would will either a decline or increase in population numbers beyond the lower or upper limits of natural or historical variation. On the lower side, one would expect imminent loss of the species from the area. For example, population viability analyses incorporate knowledge of growth and demographics within a given population into a mathematical model of a population's reproduction and dispersal dynamics. The output of the model provides an estimate of the probability of persistence for that species within the study area, including an estimate of the critical lower threshold below which the species would have a very low probability of persistence. On the upper side, population viability analysis would estimate an excellent probability of future persistence, and one would expect such rapid growth that this species would begin displacing other species.

Ecologists typically cannot estimate specific probabilities of persistence for communities and ecological systems, as can be done for species populations. Instead, we recognize that unacceptable alteration will involve severe degradation of a resource, leading to its transformation into some other kind of system altogether (e.g., the stream flow stops, leaving a dry stream bed; a grassland becomes a woodland in the absence of fire). Such a transformation might begin with the loss of only a few highly sensitive species, although it could increasingly affect the more common and less specialized as well. (As we discuss below, the critical thresholds for all key ecological attribute together for a resource establish an "acceptable range of variation" for the resource as a whole. The Ecological Integrity Assessment Framework requires identifying the acceptable range of variation for each indicator used to keep track of each key attribute, for each resource.)

Critical thresholds may reflect either "hard" or "soft" ecological thresholds (sensu Holling 1973). Hard thresholds mark conditions beyond which species populations or ecological systems change irreversibly; "soft" thresholds only mark conditions of significant management concern.

When a key ecological attribute crosses either a hard or soft critical threshold, the resource itself may not experience either immediate or abrupt change. The resource may initially only lose its capacity to resist change triggered by new disturbances and/or its capacity to recover following a new disturbance. Once a resource suffers such a loss of resistance or resilience, however, it may take only a slight additional change to trigger further alteration away from its acceptable range of variation. For example, the suppression of fire in an aspen woodland for more than a few decades could leave it vulnerable to the arrival of seeds from other nearby communities, that could lead to the replacement of the dominant tree cover by Douglas fir and other conifers that promote changes in soils and ground-cover vegetation that attract different fauna that further transform community dynamics, and so forth. Similarly, a decline in population size or density for a species below some threshold may make it significantly less able to recover following some new disturbance such as a particularly harsh drought or the spread of a virus. Alternatively, when one or more key ecological attributes for an ecological community or system cross critical thresholds, the result initially may be only the loss of a few highly sensitive or specialized species. Nevertheless, such a loss may constitute an unacceptable degradation in the ability of the resource to sustain its full spectrum of biological diversity. Additionally, the changes that ensue when a key ecological attribute passes some critical threshold may take considerable time to play out, particularly in systems with very long-lived species. Nevertheless, once set in motion, such chains of consequences may be difficult to reverse.

Working with the acceptable range of variation does not mean that planners must describe the precise indicator values, or target measures to be managed for. Instead, they only need to describe those particular *limits* of variation among key ecological attributes and their indicators, within which they expect the resource to retain its critical biological characteristics. Estimating the acceptable range of variation for each indicator answers the crucial questions, *how much alteration of a key ecological attribute is too much*? When is the resource approaching levels of impairment? And, *how much restoration is likely to be adequate*? Managing conservation resource values within their acceptable ranges of variation in turn does not mean managing for all the variation that the resource might experience under undisturbed conditions. Instead, it means managing only for an *envelope of conditions* that together are "sufficient" for resource persistence, function, and for achieving related management goals.

Estimating the acceptable range of variation for every indicator may be a challenge. It requires some knowledge of the natural (e.g., historic) range of variation for all key ecological attributes and their indicators. It also typically requires knowledge from similar locations where common forms of degradation have taken place. Fortunately, even initial approximations about the acceptable range of variation for an indicator provide hypotheses on which both to begin management and to begin research to improve the initial estimates.

Thresholds of Imminent Loss

Our discussion up to this point has focused on the thresholds or limits that define the acceptable ranges of variation in the indicators for each key ecological attribute of a focal ecological resource. However, there is another kind of threshold to consider – a "threshold of imminent loss." These are hard thresholds.

The alteration of one or more key ecological attributes beyond their acceptable ranges of variation can reach a further threshold, beyond which the focal resource will almost certainly fail unless the situation is quickly reversed. For species, failure in a project area would involve a collapse of population beyond a point of no return (other than through reintroduction); or involve an expansion of population sufficient to result in potentially irreversible changes to other aspects of the larger ecosystem. For communities and ecological systems, failure in a project area would mean potentially irreversible transformation into – or replacement by – some other kind of community or system.

It is crucial that managers recognize the potential existence of a threshold of imminent loss for focal resources, for which one or more key ecological attributes lie outside their acceptable ranges of variation. This recognition will help managers determine if a focal resource is at risk of failure within the immediate future (e.g., 15-25 years) as a result of the condition (or trend) in those altered key ecological attributes. More precisely, managers must know how to recognize this extreme threshold with the indicators that they have selected. Resource managers should not miss detecting when a focal resource is at risk of imminent failure. On the other hand, managers do not want to undertake massive and costly rescue efforts for focal resources that in fact are not at risk of such imminent failure. Unfortunately, too, managers may not want to expend effort on a focal resource, for which success is too unlikely or the costs of the rescue too high to justify the effort. Decisions on rescuing species that have crossed a threshold of imminent loss – for example, the California condor, or the black-footed ferret in the U.S. – partly depend on whether we can tell if the species can be rescued, and at what cost.

Estimating thresholds of imminent loss for every indicator will also pose a challenge. Most crucially, it requires knowledge of how the focal resource – or a similar ecological resource – would be likely to fail. Such knowledge can come from locations where common forms of degradation have taken place, or from ecological models. As with the estimating of acceptable ranges of variation, fortunately, even initial approximations about thresholds of imminent loss for an indicator will provide hypotheses on which both to begin management and to begin research to improve the initial estimates.

Organizing Focal Resource Information Using a Standard Scorecard

The Ecological Integrity Assessment Framework organizes information in a clear hierarchy to guide the management of a Park's ecological resources. It calls for the selection of (1) a limited suite of coarse filter/fine filter focal ecological resources with which to guide management. For each focal resource, it calls for the identification of (2) a limited suite of key ecological attributes to characterize the focal resource and its most crucial dynamics. For each key ecological attribute, it calls for the identification of (3) a limited suite of indicators with which to measure the status of the attribute. For each indicator, it calls for (4) estimates of the acceptable range of variation and a threshold of imminent loss. The definitions of 'acceptable range of variation' and 'threshold of imminent loss' establish an objective basis for managers to assess the status of key ecological attributes and therefore to assess the status of each focal ecological resource. In turn, the status of the entire suite of focal ecological resources provides crucial information with which to guide management, with the focal resources standing in for all biodiversity across the project area.

Full implementation of the EIAF requires the collecting of monitoring data on the selected indicators. Each cycle of monitoring will produce a new set of data on the status of each focal resource.[2] The EIAF simplifies the task of "rolling up" the resulting information, from indicator to focal resource, by defining three categories – termed "rating increments" – to summarize the status of every indicator, as follows:

> **Acceptable**: The indicator lies within its acceptable range of variation.
>
> **Potential Concern**: The indicator lies outside its acceptable range of variation but not outside its threshold of imminent loss.
>
> **Imminent Loss**: The indicator lies outside its threshold of imminent loss.

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[2] Further discussion of monitoring program design lies beyond the scope of this document.

Table 9 includes an example of one indicator with rating increments expressed using these categories.

Table 9. Example of an indicator including rating criteria.

Level	Term	Description
Attribute and Indicator	Key Attribute	Dominance of Native Species
	Indicator	Relative Total Cover of Native Plant Species
	Definition	Percent cover of the plant species that are native, relative to total cover
Indicator Ratings	Acceptable	90-99% relative cover of native plant species
	Potential Concern	50-90% relative cover of native plant species
	Imminent Loss	<50% relative cover of native plant species

Table 10, in turn, describes how the information on indicators "rolls up" to provide information on the status of key ecological attributes and focal ecological resources. This table highlights the crucial difference between an indicator and a key ecological attribute. An indicator is merely the means to estimate the status of a key attribute. Where managers must use more than one indicator to get a clear picture of the status of a key attribute, they should use the weight of the evidence to determine the status of the key attribute. As stated in its definition, however, a key ecological attribute is a critical aspect of the focal resource, the impairment of which will result in impairment of the entire focal resource. Thus, if any key ecological attribute for a focal resource falls outside its acceptable range of variation, the entire focal resource suffers.

Table 10. Integration of indicator information to establish high-level information on the status of a focal ecological resource

Measurement at this level…	…informs the assessment of…	…through the application of this rule:
Indicators	Key ecological attribute status	• If a single indicator is used to assess the status of a key ecological attribute, its rating determines the rating for the key ecological attribute. • If more than one indicator is used, an average of the ratings of all indicators determines the rating for the key attribute. Tied ratings are resolved in favor of the more severe rating increment.
Key ecological attribute status	Focal ecological resource	• The focal resource receives a rating of *Imminent Loss* if any key attribute receives this rating. • The focal resource receives a rating of *Potential Concern* if any key attribute receives this rating and none receives a more severe rating. • The focal resource receives a rating of *Acceptable* only if all key attributes receive this rating.

These rules result in the following standard categories to describe the status of each focal ecological resource in a project area:

> **Acceptable:** The focal resource is not significantly impaired and does not require intensive management to maintain integrity.
>
> **Potential Concern:** The focal resource is impacted by human or other environmental factors that require some management to restore full integrity but that do not require immediate, massive intervention to prevent loss of the resource altogether.
>
> **Imminent Loss:** The focal resource is significantly impacted by human or other environmental factors that require immediate, massive intervention merely to prevent loss of the resource altogether.

The EIAF methodology thus lends itself to the use of a 'scorecard' to organize information on each focal ecological resource. A scorecard becomes the primary vehicle to document the status of each indicator at a given point in time, and can capture changing conditions as management proceeds. Table 11 shows an example scorecard for a hypothetical focal resource within a project area; grey highlighted cells indicate the current status of each indicator. The table uses the three summary integrity factors – Landscape Context, Condition, and Size – as a convenient basis for organization.

The hypothetical wetland system illustrated in Table 9 would receive an overall rating of "Potential Concern" based on the presence of not just one but three key ecological attributes that individually warrant ratings of "Potential Concern". None of the key ecological attributes receives a rating of "Imminent Loss." Two key ecological attributes are assessed using multiple indicators; one of these, "Landscape Composition," is represented by three indicators, two of which receive ratings of "Acceptable" and the other of which receives a rating of "Potential Concern." The weight of the evidence in this case leads to a rating of "Acceptable" for the key attribute overall.

Table 9 also illustrates the use of indicators that capture information about stressors rather than natural variability *per se*. Key ecological attributes are meant to capture information about a focal ecological resource in the absence of significant stress. In principle, therefore, indicators of key ecological attributes generally should not include information on stressors. In practice, however, information on a stressor can play a useful role in gauging the status of a key ecological attribute, when the stressor plays a dominant role in potential alterations to that key attribute. Thus, for example, a planning team might construct an indicator for native plant species composition based on the relative abundance of non-native species or aggressive native species on-site. The use of such indicators requires a comparative analysis of many examples, in order to verify the correlation between the stressors (non-native species abundance) and the status of the key ecological attribute (native plant species composition).

Table 11. Example of an ecological integrity scorecard for a hypothetical wetland system.

Scope	Key Ecological Attribute	Indicator	Indicator Definition	Indicator Rating Criteria		
				Acceptable	Potential Concern	Imminent Loss
Landscape Context	Landscape Composition	Adjacent Land Use	Addresses the intensity of human dominated land uses within 100 m of the wetland.	Average Land Use Score = 0.80-1.0	Average Land Use Score = 0.4-0.80*	Average Land Use Score = < 0.4
	Landscape Composition	Buffer Width	Wetland buffers are vegetated, natural (non-anthropogenic) areas that surround a wetland	Wide > 50 m*	Narrow. 25 m to 50 m	Very Narrow. < 25 m
	Landscape Composition	Landscape Predictors of Hydrologic Alteration	Onsite or adjacent land uses and water uses that could result in changes to wetland hydrology.	Low intensity alteration such as roads at/near grade, small diversion or ditches (< 1 ft. deep) or small amount of flow additions*	Moderate intensity alteration such as 2-lane road, low dikes, roads w/culverts adequate for stream flow, medium diversion or ditches (1-3 ft. deep) or moderate flow additions.	High intensity alteration such as 4-lane Hwy., large dikes, diversions, or ditches (>3 ft. deep) able to lower water table, large amount of fill, or artificial groundwater pumping or high amounts of flow additions.
	Landscape Pattern	Percentage of unfragmented landscape within 1 km.	Measures extent to which landscape lacks barriers to the movement of species, water, nutrients, etc. between natural ecological systems	Embedded in 60-100% unfragmented natural landscape; internal fragmentation minimal	Embedded in 20-60% unfragmented natural landscape; Internal fragmentation moderate*	Embedded in < 20% unfragmented natural landscape. Internal fragmentation high
Condition	Plant Assemblage Composition	Percent of Cover of Native Plant Species	Percent cover of the plant species that are native, relative to total cover (sum by species)	85-< 100% cover of native plant species*	50-85% cover of native plant species	<50% cover of native plant species
	Plant Assemblage Composition	Invasive Species – Plants	Percent of marsh dominated by invasive, aggressive plants.	Native species such as *Typha* and *Phragmites* and/or other non-native invasive species occupy < 10% of wetland*	Native species such as *Typha* and *Phragmites* and/or other non-native invasive species occupy 10-50% of wetland	Native species such as *Typha* and *Phragmites* and/or other non-native invasive species occupy >50% of wetland
	Hydrologic Regime	Flashiness Index	Measures the variability in water depth fluctuations it compared to reference data	Flashiness Index = 1.0 - 2.0	Flashiness Index = between 2.0 -3.0 if wetland is NOT associated with riverine*	Flashiness Index = > 3.0 if wetland is NOT associated with riverine environment

* Indicates the current scoring for a given indicator (also with a gray background).

Table 11 (continued). Example of an ecological integrity scorecard for a hypothetical wetland system.

Scope	Key Ecological Attribute	Indicator	Indicator Definition	Indicator Rating Criteria		
				Acceptable	**Potential Concern**	**Imminent Loss**
Size	Absolute Size	Absolute Size	The current size of the wetland relative to other examples of this type	> 25 acres (10 ha)	1 to 25 acres (0.4 to 10 ha)*	< 1 acre (<0.4 ha)
	Relative Size	Relative Size	The current size of the wetland divided by the total potential size of the wetland multiplied by 100	Wetland area < Abiotic Potential; Relative Size = 90 – 100% ; (< 10% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc.*	Wetland area < Abiotic Potential; Relative Size = 75 – 90%; 10-25% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc	Wetland area < Abiotic Potential; Relative Size = < 75%; > 25% of wetland has been reduced, destroyed or severely disturbed due to roads, impoundments, development, human-induced drainage, etc

* Indicates the current scoring for a given indicator (also with a gray background).

The scorecard provides a clear mechanism to capture information on each focal resource at a given point in time. As a practical starting point, the detection of one or more key ecological attributes of “Potential Concern” should trigger increased attention to determine an appropriate management response. Likewise, the detection of any key ecological attributes in the “Imminent Loss” category should lead to urgent action. Thus, while the scorecard can be used to generate an overall rating for each focal resource, managers must also track the status of individual indicators and key attributes to obtain guide their decisions and actions.

It is important to remember that all efforts to assess ecological integrity necessarily rest on only an approximate understanding of the system. In reality, ecosystems are far too complex to be fully represented by a static suite of metrics and attributes. Our metrics, indices and scorecards must be flexible enough to allow change over time as our knowledge grows. Additionally, it is crucial that managers clearly articulate their reasoning and the evidence they use to support it, in order to foster communication and understanding among people with different backgrounds, goals, and points of view.

V. Next Steps

Moving from identifying focal ecological resources and defining the criteria for ecological integrity of these resources to managing those resources involves four tasks: (1) identifying desired conditions for each focal resource based on its key ecological attributes and potentially also on criteria that take into account other Park unit priorities; (2) identifying stressors potentially affecting – or anticipated to affect – the status of each focal resource through its key ecological attributes; (3) setting strategies and a timeline for action to establish or ensure the continuity of desired conditions; and (4) establishing objectives with performance metrics or benchmarks with which to evaluate these actions. The first task, to identify desired conditions, is addressed in the NPS Interim Technical Guidance on Defining Meaningful Desired Conditions for Natural Resources. In this latter document, the desired condition concept is presented to show how ecological criteria are developed along with institutional and social criteria to set management targets from which stressors, strategies and objectives are later developed. Guidance for tasks 2-4 will be developed in an addendum to this document, and/or technical guidelines for Resource Strategies, Fire Management Plans or Resource Implementation Plans, such as River Plans and Vegetation Management Plans. Specific suggestions for applying this guide are:

1) Fine tune scoping of biological and ecological resources in foundation documents;
2) Integrate into Resource Stewardship Strategies;
3) Use as a basis for analysis of alternatives on management zones in General Management Plans;
4) Use as a framework for reporting condition for GPRA and Performance Management;
5) Use for collaborative planning among several organizations to preserve wide-ranging species;
6) Apply to climate change scenarios including identification of resiliency-based KEAs.

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