Assessing the Condition of Ecosystems To Guide Conservation and Management:

An Overview of NatureServe's Ecological Integrity Assessment Methods

[DRAFT REPORT]

NatureServe

A Network Connecting Science With Conservation

Assessing the Condition of Ecosystems To Guide Conservation and Management

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Photographs on the front cover:
Catskills Dwarf-shrub Bog, with Pitcher plant inset.

Photo by Don Faber-Langendoen

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[under development]

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As is evident from the results in this report, we have greatly benefited from a variety of recent efforts to address ecosystem condition and integrity. Overall the insights of a 3-level approach developed by EPA have greatly influenced the direction of our work. For wetlands these include the Ohio Rapid Assessment Methods (ORAM) developed by the Ohio EPA and led by John Mack, and the California Rapid Assessment Method (CRAM), led by Josh Collins, Marta Sutula and others. For uplands, the opportunity of working with Greg Shriver, Brian Mitchell, Geri Tierney, and James Gibbs was very rewarding in understanding how to select and apply level 3 metrics for northeast U.S. forests. Although we differ in various ways from those methods in how we approach the primary goal of ecological integrity assessments, we nonetheless have benefited greatly from their publications, phonecall conversations, and workshop discussions.

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EXECUTIVE SUMMARY

There has been a strong interest in developing ecological integrity assessment (EIA) methods to assist in conservation and management of ecosystems. Concerns have changed from “how much of it is out there?” and “is it protected? to “how is it doing?” and“what condition is it in?” Our **ecological integrity assessment** method builds on NatureServe and the Network of Natural Heritage Program’s historic approaches to assessing condition, but has adapted them by building on the variety of existing wetland rapid assessment methods and the 3-level approach of the U.S. Environmental Protection Agency and others. The method emphasizes metrics that are condition-based, separate from those that are stressor-based.

The assessment uses the following steps:

1) outlines a general conceptual model that identifies:
   a) the major ecological attributes (landscape context, size, and condition, including vegetation, soils, hydrology),
   b) provides a narrative description of declining integrity levels based on changes to those ecological attributes, and
   c) uses a metrics-based approach to assess the levels of integrity.
2) uses ecological classifications at multiple classification scales to guide the development of the conceptual models, to allowing improved refinement of assessiing attributes, as needed.
3) uses a three level assessment approach – (i) remote sensing, (ii) rapid ground-based, and (iii) intensive ground-based metrics – to guide development of metrics. The 3-level approach is intended to provide increasing accuracy of ecological integrity assessment, recognizing that not all conservation and management decisions need equal levels of accuracy.
4) identifies ratings and thresholds for each metric based on “normal’ or “natural range of variation” benchmarks.
5) provides a scorecard matrix by which the metrics are rated and the ratings integrated into an overall set of indices of ecological integrity for the ecosystem at a site.
6) provides tools for adapting the metrics over time as new information and methods are developed.

For NatureServe and the Network, when working with conservation partners who maintain sites for their biodiversity conservation value, our primary interest in EIAs is to agree on a set of ecosystem types, whose ecological integrity is assessed consistently, at multiple levels, across a suite of sites, with a primary goal of conducting repeat assessments to ensure that ecological integrity is being maintained or improved.

Other applications of ecological integrity assessments include ongoing state level inventory and assessments by the Network of Natural Heritage Programs, wetland migitation, ecosystem monitoring in National Parks, and a national wetland condition assessments, among others.

We provide an overview of the metrics and their ratings for the various assessment levels, as well as detailed protocols and scorecards for metrics at Level 1 (generic for all natural ecosystems) and Level 2 (specific to major ecological formations, with variants by macrogroup and system as needed). Level 3 metrics are still under development and are expected to be much more diverse across ecosystems. NatureServe is upgrading its Biotic database to manage and store the ecological assessment methods.

NatureServe is upgrading its Biotic database to contain:

a) a metrics database that describes the metrics and protocols to assess integrity (comparable to how NatureServe maintains a database of conservation status rank factors)
b) ability to maintain 3 levels of EORANKSPECS (level 1, 2, 3) and,
c) a revised EORANK file that allows ecologists to specify the level of rank being applied (Level 1, 2, or 3) and the metrics used to rank an occurrence.

We are encouraging subnational ecologists to adopt a single, set of consistent factors, all scaled to a the same range for ranking occurrences, rather than adjusting their rank standard based on subnational priorities. At the same time, Our efforts to assess ecological integrity are approximations of our current understanding of any ecosystem. Programs and partners are encouraged to test and refine these metrics, keeping in mind the overall definitions and purposes of ecological integrity assessments.

A. INTRODUCTION

There has been a strong interest in developing ecological integrity assessment methods (EIAs) to guide conservation and management practices, such as choosing sites for conservation, setting performance expectations for restoration or mitigation, or tracking trends in condition over time. Such approaches are being widely promoted among a number of agencies, conservation organizations, and research scientists who focus on the critical role of indicators for assessing ecological integrity of communities and ecosystems (Harwell et al. 1999, Andreasen et al. 2001, Young and Sanzone 2002, U.S. EPA 2002a, Parrish et al. 2003, Faber-Langendoen et al. 2008a, Tierney et al. 2009).

Assessing the current ecological integrity of an ecosystem requires developing measures of the structure, composition, and function of an ecosystem as compared to reference or benchmark ecosystems operating within the bounds of natural or historic disturbance regimes (Lindenmayer and Franklin 2002, Young and Sanzone 2002). However, selection and development of indicators to measure ecological integrity can be challenging, given the diversity of organisms and systems, the large number of ecological attributes that could be measured, and concerns over cost-effectiveness and statistical rigor, and loss of adequate reference sites to guide the assessment (Brewer and Menzel 2009). There is a need for a set of methods that provides guidance on the range of options for assessing ecological integrity, scaled both in terms of the level of ecosystem type that is being assessed, and the level of information required to conduct the assessment.

A.1 Overview

A.1.1. Purpose of this Report

The purpose of this report is to explain NatureServe's Ecological Integrity Assessment (EIA) methods that are available for use by its Network of Natural Heritage Programs and by agency and non-profit partners. For over twenty-five years, NatureServe has advanced the Natural Heritage Methodology for documenting the viability and integrity of individual occurrences of species and ecosystems[1]. Our **ecological integrity assessment** method builds on that methodology, but has adapted them by building on a variety of existing rapid assessment methods (Mack 2001, Collins et al. 2006, 2007), and the 3-level approach of the U.S. Environmental Protection Agency and others (Brooks et al. 2004, US EPA 2006, Faber-Langendoen et al. 2006, 2008a).

We outline a variety of new methods to structure our selection of indicators for all natural ecosystems, including a) use of a conceptual model of ecological integrity based on an

[1]The Natural Heritage methodology was originally developed by The Nature Conservancy (TNC), but Heritage methods staff transferred to NatureServe when it was formed in 2000. Since then, NatureServe has worked with the Network of Natural Heritage Programs to maintain and improve the methodology, while continuing to collaborate with TNC.

indicators approach, b) an improved hierarchical framework for ecosystem classification, c) a three level approach to the development of metrics (remote, rapid, intensive), d) detailed guidance on metrics and their ratings across the first two levels, and e) a report card structure for aggregating metric ratings by major ecological attributes (landscape context, size, vegetation, hydrology and soils). We hope this report will foster further testing and application and encourage standards for assessing ecological integrity beyond project specific needs, so that a comprehensive view of the status of ecosystem types across their range may emerge.

A.1.2. Purposes of Ecological Integrity Assessments

The purpose of an ecological integrity assessment and of assigning an index of ecological integrity (what the Network calls an EO rank) is to provide a succinct assessment of the current status of the composition, structure and function of occurrences of a particular ecosystem type and give a general sense of conservation value. These assessment methods can be used to address a number of objectives, including to:

- assess ecological integrity on a fixed, objective scale (global EO rank, subnational[2] rank).
- compare ecological integrity of various occurrences of the same element, to determine the best examples and support selection of sites for conservation priority, recognizing that issues such as cost, practicality, etc. also affect priorities.[3]
- inform decisions on monitoring individual ecological attributes of a particular occurrences (e.g., floristic quality, vegetation structure, hydrology).
- provide an aggregated index of integrity to interpret monitoring data, including tracking the status of ecological integrity over time.

Other related purposes within the Network include:

- Contribute to information on an ecosystem type's overall conservation status ("extinction risk"), whether for global, national, and subnational Element conservation status ranks (G rank, N rank, and S rank). The "number of good ccurrences" or "percent area of an element that is good condition" are factors relevant to assessing the extinction risk.

[2]In this document, the term "subnation" will refer to the first order subdivision of a nation (*e.g.*, state, province, district, department).

[3] Although Element and Element occurrence (EO) ranks help to set conservation priorities, they are not the sole determining factors. The determination of priority occurrences for conservation action will include not only the conservation status of the Element and the likelihood of persistence of the occurrence, but will also include consideration of other factors such as the taxonomic distinctness of the Element; the genetic distinctness of the EO; the co-occurrence of the Element with other Elements of conservation concern at a site; the likelihood that conservation action will be successful; and economic, political, and logistical considerations.

- Prioritize field survey work. Occurrence ranks may be used effectively in conjunction with Element ranks to guide which occurrences should be recorded and mapped (see NatureServe 2002, Section 6, EO Tracking), and to help prioritize occurrences for purposes of conservation planning or action, both locally and rangewide.

- Inform species occurrence ranks. Rarely, for species dependent on particular habitats, and which may themselves be hard to track, the occurrence rank of the habitat may serve as a guide for the species EO ranks.

These objectives are inter-related, and can be jointly addressed as we revise our current methodology. However, we expect that individual purposes and projects may require additional tailoring of the method.

A.2. The Scope of Ecological Integrity

A.2.1. Definition

Building on the related concepts of biological integrity and ecological health, ecological integrity is a broad and useful endpoint for ecological assessment and reporting (Harwell et al. 1999). "Integrity" is the quality of being unimpaired, sound, or complete. Ecological integrity can be defined as "an assessment of the structure, composition, and function of an ecosystem as compared to reference ecosystems operating within the bounds of natural or historic disturbance regimes" (adapted from Lindenmayer and Franklin 2002, Young and Sanzone 2002, Parrish et al. 2003). To have ecological integrity, an ecosystem should be relatively unimpaired across a range of ecological attributes and spatial and temporal scales (De Leo and Levin 1997). The notion of naturalness depends on an understanding of how the presence and impact of human activity relates to natural ecological patterns and processes (Kapos et al. 2002). Identification of reference or benchmark conditions based on natural or historic ranges of variation, although challenging, can provide a basis for interpretation of ecological integrity (Swetnam et al. 1999). These general concepts needs greater specificity to become a useful guide for conducting ecological integrity assessments, something we develop in Section B.

Our approach to assessing ecological integrity is similar to the Index of Biotic Integrity (IBI) approach for aquatic systems. The original IBI interpreted stream integrity from twelve metrics that reflected the health, reproduction, composition and abundance of fish species (Karr and Chu 1999). Each metric was rated by comparing measured values with values expected under relatively unimpaired (reference standard) conditions, and the ratings were aggregated into a total score. Building upon this foundation, others suggested interpreting the integrity of ecosystems by developing suites of indicators or metrics comprising key biological, physical and functional attributes of those ecosystems (Harwell et al. 1999, Andreasen et al. 2001, Parrish et al. 2003). We follow that lead by developing an index of ecological integrity based on metrics of biotic and abiotic condition, size, and landscape context.

A.2.2. Ecological Integrity and Other Assessments

Ecological integrity may only be one aspect of an ecosystem assessment. Other aspects include 1) conservation status / biodiversity value, which includes aspects of ecosystem irreplaceability, 2) Wetland functional assessments or ecosystem services, such as flood control, nutrient retention (Hruby 2001, Fennessy et al. 2004), 3) specific resource productivity, such as saw timber or forage. The first aspect, assessing the conservation status and irreplaceability value of ecosystems types and occurrences, can be part of a risk assessment process, where more irreplaceable occurrences are preferentially targeted for threat abatement or subject to greater degree of protection, thereby avoiding further losses. This assessment can begin by assessing the relative conservation status (or risk of extirpation) of a given type. For example, the Heinz Center (2002) uses the "At-risk wetland plant communities" (based on NatureServe's conservation status assessment approach), as an indicator of overall wetland or aquatic condition.

Functional assessments have been widely developed for wetlands (e.g., the Hydrogeomorphic Approach of Brinson et al. 1993). Similar to ecological integrity assessments, functional assessments estimate the structure, composition, and processes of ecosystems. However, these methods use this information to evaluate the capacity of wetlands to perform certain functions or ecosystem services, independently of how those services relate to ecological integrity. For example, metric ratings that assess flood / storm water control or wildlife habitat utilization may not have a direct correspondence to metrics for hydrologic condition as it relates to ecological integrity (Hruby 2001, Hruby 2004). In an ecological integrity assessment, an ecosystem is considered to have excellent integrity if it performs all of its functions or processes within an expected range of natural variation for that type.

Other perspectives on the condition of an ecosystem may include sustaining levels of forest or rangeland productivity. In the context of an overall assessment of natural resources and biodiversity, consideration will need to be given to balancing the relative goals of any assessment, and determining where on the landscape these various goals may be achieved. Ecological integrity assessments provide an important piece of information on the historic, natural ranges of variation on ecosystem composition, structure, and processes.

A.3. Ecological Classification

The success of developing indicators of wetland ecological integrity depends on understanding the structure, composition, and processes that govern the wide variety of ecosystem types (we use the term "ecosystem" in a generic sense to refer to both ecological communities and systems). Ecological classifications can be helpful tools in categorizing this variety. They help ecologists to better cope with natural variability within and among types so that differences between occurrences with good integrity and poor integrity can be more clearly recognized. Classifications are also important in establishing "ecological equivalency," for example, in providing guidance on how an impacted salt marsh can be restored to a salt marsh with improved integrity. There are a variety of classifications and ecoregional frameworks for structuring ecological integrity assessments. Here we focus on two classifications in particular: the International Vegetation Classification (IVC) and Ecological Systems.

The **International Vegetation Classification** covers all vegetation from around the world. In the United States, its national application is the **USNVC**, supported by the Federal Geographic Data Committee, NatureServe, and the Ecological Society of America, with other partners (FGDC 2008, Faber-Langendoen et al. 2009, Jennings et al. 2009). The IVC and NVC were developed to classify both wetlands and uplands, and identify types based on vegetation composition and structure and associated ecological factors. At the highest level of Formation Class there are 8 broad classes, and 7 other nested hierarchical levels permit resolution of types from broad-scale formations to fine-scale associations (Table 1).

Table 1. The following table illustrates the eight levels of the USNVC hierarchy, using salt marshes as an example. Also show is an example of how Ecological Systems can be linked to the Hierarchy. The Acadian Coastal Salt Marsh system falls within the Eastern North American Atlantic Salt Marsh macrogroup, but at the group level it combines marsh zones within a geographic area, whereas the group level separates low, high, brackish and tidal flat/salt panne groups. The Spartina patens alliance occurs in the high salt marsh group across a range of Atlantic and Guf Coast marshes.

USNVC Hierarchy	Pilot NVCTypes
Upper Levels	
Formation Class	Low Shrubland & Grassland
Formation Subclass	Temperate & Boreal Shrubland & Grassland
Formation	Salt Marsh
Mid-Levels	
Division	Temperate & Boreal Atlantic Coastal Salt Marsh
Macrogroup	Eastern North American Atlantic Salt Marsh
Group	North American Atlantic High Salt Marsh
Lower Levels	***Acadian Coastal Salt Marsh** System*
Alliance	Spartina patens Salt Marsh
Association	Spartina patens - Distichlis spicata - (Juncus gerardii) Salt Marsh

The USNVC meets several important needs for conservation and resource management. It provides:

- a multi-level, ecologically based framework that allow users to address conservation and management concerns at scales relevant to their work.
- characterization of ecosystem patterns across the entire landscape or watershed, both upland and wetland.

- information on the relative rarity of types. Each association has been assessed for conservation status (extinction risk).
- relationships to other classification systems, particularly state natural Heritage classifications that are explicitly linked to the NVC types, but also other similar classifications, such as the NWI wetland classification (Cowardin et al. 1979), SAF cover type classification (Eyre 1980).
- a federal standard for all federal agencies, facilitating sharing of information on ecosystem types (FGDC 2008).

A second, related classification approach, the **Ecological Systems** classification (Comer et al. 2003), can be used in conjunction with the IVC and USNVC. Ecological systems provide a spatial-ecologic perspective on the relation of associations and alliances (fine-scale plant community types), integrating vegetation with natural dynamics, soils, hydrology, landscape setting, and other ecological processes. They can also provide a mapping application of the NVC, much as soil associations help portray the spatial-ecologic relations among soil series in a soil taxonomic hierarchy. Systems types facilitate mapping at meso-scales (1:24,000 – 1:100,000). Increasingly, comprehensive systems maps are becoming available across the country (Comer et al. 2007, www.landscope.org). Systems are somewhat comparable to the Group level of the revised NVC hierarchy, and can be linked to higher levels of the NVC hierarchy, including macgroups and formations. Systems meet several important needs for conservation, management and restoration, because they provide:

- an integrated biotic and abiotic approach that take advantage of the hydrologic and abiotic perspective of HGM and site classifications with that of the vegetation emphasis of the NVC. They can be more effective at constraining both biotic and abiotic variability within one classification unit than either of the two, and they should facilitate development of ecological indicators.
- comprehensive maps of all ecological system types are becoming available.
- explicit links to the USNVC, facilitating crosswalks of both mapping and classifications.
- and more…

These two classifications can be used in conjunction with ecoregional frameworks to sort out the ecological variability that may affect ecological integrity.

B. Ecological Integrity Assessments

Our approach to establishing ecological integrity assessment methods builds on the NatureServe methodology for conducting ecological integrity assessments (Stein and Davis 2000, Brown et al. 2004, Faber-Langendoen et al. 2008). We develop the assessments using the following steps; we:

1) outline a general conceptual model that identifies the major ecological attributes, provide a narrative description of declining integrity levels based on changes to those

ecological attributes, and introduce the metrics-based approach to measure those attributes and assess their levels of degradation.

2) use ecological classifications at multiple classification scales to guide the development of the conceptual models, to allowing improved refinement of assessiing attributes, **as needed**. E.g., the characteristics of vegetation, soils or hydrology for tropical forests differs strongly from that of temperate forests, the characteristics of temperate Red Spruce-Fir Forest differ in many respects from temperate Longleaf Pine Woodland, and the characteristics of montane Red Spruce-Balsam Fir Forest may differ in some respects from that of lowland Red Spruce–Hardwood Forest.

3) use a three level assessment approach – (i) remote sensing, (ii) rapid ground-based, and (iii) intensive ground-based metrics – to guide development of metrics. The 3-level approach is intended to provide increasing accuracy of ecological integrity assessment, recognizing that not all conservation and management decisions need equal levels of accuracy.

4) identify ratings and thresholds for each metric based on “normal’ or “natural range of variation” benchmarks.

5) provide a scorecard matrix by which the metrics are rated and integrated into an overall index of ecological integrity.

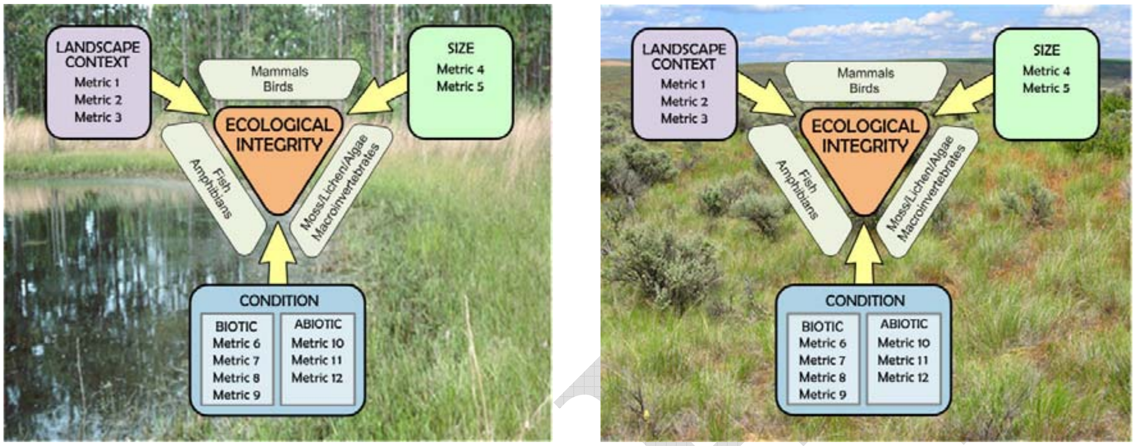
6) provide tools for adapting the metrics over time as new information and methods are developed.

B.1. Conceptual Model and Metrics

B.1.1. Conceptual Model

A conceptual ecological model that identifies the major ecological attributes and linkages to known stressors or agents of change is a useful tool for guiding ecological integrity methods (Noon 2003). We developed a general conceptual model that identifies a) **major ecological attributes** of ecosystems, including the condition of vegetation, soils (and hydrology for wetlands), landscape context, and size that help characterize overall structure, composition and process, and b) important drivers and stressors acting upon ecosystems (Fig. 1, Table 2). Other major attributes, such as birds, amphibians, and macroinvertebrates can also be assessed where resources, time and field sampling design permit. The model is fairly intuitive, but a key component is that integrity incorporates spatial aspects of ecological integrity using both size and landscape context attributes.

Figure 1. Conceptual Model for Assessing Ecological Integrity
The major ecological attributes of ecosystem integrity are shown for upland and wetland models. Ecosystem drivers, such as climate, geomorphology, and natural disturbances maintain overall integrity, whereas stressors act to degrade it. See also Table 1.



WETLANDS **UPLANDS**

Table 2. Example of an ecological integrity table, based on the conceptual model of major ecological attributes and rank factors (see Fig 1). Indicators are identified for each major ecological attribute. Stressors can be described using checklists (wetland example).

Rank Factor	Major Ecological Attribute	Indicator
LANDSCAPE CONTEXT	**Landscape Structure**	Landscape Connectivity
		Buffer Index
		Surrounding Land Use Index
	Landscape Stressors	Landscape Stressors Checklist
SIZE	**Size**	Patch Size Condition
		Patch Size
CONDITION	**Vegetation**	Vegetation Structure
		Organic Matter Accumulation
		Vegetation Composition
		Relative Total Cover of Native Plant Species
	Vegetation Stressors	Vegetation Stressors Checklist
	Soils (including physico-chemical	Physical Patch Types
		Water Quality
		Soil Surface Condition
	Soils Stresors	Soils Stressors Checklist
	Hydrology (wetlands)	Water Source
		Hydroperiod
		Hydrologic Connectivity
	Hydrology Stressors (wetlands)	Hydrology Stressors Checklist

The conceptual model helps guide the selection of indicators, organized across a standard set of ecological attributes and factors (e.g., Harwell et al. 1999, Young and Sanzone 2002, Parrish et al. 2003). The indicators are placed within the interpretive framework provided by the conceptual model, organizing the metric by **major ecological attributes –** broad attributes that have an important (driving) function in the viability or integrity of the element – and by **rank factors** (Table 2).

B.1.2. Indicators and Metrics

Indicators provide the specificity needed to assess the major ecological attributes. **Metrics** can be thought of as the measurable expressions of an indicator. For example, "Relative Total Cover of Native Plant Species" is a compositional indicator of the Vegetation attribute; the metric used to quantify this indicator is "Total cover of exotic species subtracted from total cover of all vegetation and divided by 100.". Similarly, "organic matter accumulation" is a structural indicator of the Vegetation attribute; the metric used to quantify this indicator for forested wetlands may be "coarse woody debris - volume / ha of fallen stems over 10 cm diameter." Metrics and their protocols need to be described to ensure consistency in the assessment and monitoring process (Oakley et al. 2003).

The primary emphasis of the indicators and metrics is on measuring a relevant attribute of the ecosystem itself that responds to stressors. We refer to these as "**condition metrics**." We can also measure the stressors themselves, but information from these metrics provides only an indirect measure of the status of the system – we will need to infer that changes in the stressor correspond to changes in the condition of the system. We refer to these as "**stressor metrics.**" We provide a catalogue of possible stressors at a site (stressor checklists) to guide interpretation and possible correlations between ecological integrity and stressors.

We prefer to use condition metrics separate from stressors, in order to independently assess the effects of stressors on condition, but occasionally a stressor metric is substituted for a condition metric when measuring condition is challenging or not cost-effective. For example, the "Surrounding Land Use Index" is a stressor metric that substitutes for a condition metric characterizing the surrounding landscape. The basic goal is an accurate, cost effective estimate of integrity, rather than concern to keep the model pure.

B.1.3. Definitions of Levels of Ecological Integrity

Occurrences in the natural world vary in their level of integrity due to variety of anthropogenic impacts *i.e.*, the degree to which people have directly or indirectly adversely or favorably impacted the occurrence. Working from the basic concept of ecological integrity, we can begin to define levels of integrity, using a report-card style scale. Occurrences with higher levels of integrity would generally be ranked "A", "B", or "C" (from "excellent to at least "fair" integrity), and those with significant degradation would be ranked "D" ("poor" integrity) (see Table 3). Detailed definitions for each level are provided in Table 4.

Table 3. Basic Ecological Integrity ranks

Ecological Integrity (EO) Rank Value	Description
A	Excellent estimated viability or ecological integrity
B	Good estimated viability or ecological integrity
C	Fair estimated viability or ecological integrity
D	Poor estimated viability or ecological integrity
NR	Not yet ranked
U	Unrankable

Table 4. Definition of Ecological Integrity Rank values.

Rank Value	Description
A	Occurrence is believed to be, <u>on a global scale</u>, among the highest quality examples with respect to major ecological attributes functioning within the bounds of natural disturbance regimes. Characteristics include: the landscape context contains natural habitats that are essentially unfragmented (reflective of intact ecological processes) and with little to no stressors; the size is very large or much larger than the minimum dynamic area ; vegetation structure and composition, soil status, and hydrological function are well within natural ranges of variation, exotics (non-natives) are essentially absent or have negligible negative impact; and, a comprehensive set of key plant and animal indicators are present.
B	Occurrence is not among the highest quality examples, but nevertheless exhibits favorable characteristics with respect to major ecological attributes functioning within the bounds of natural disturbance regimes. Characteristics include: the landscape context contains largely natural habitats that are minimally fragmented with few stressors; the size is large or above the minimum dynamic area, the vegetation structure and composition, soils, and hydrology are functioning within natural ranges of variation; invasives and exotics (non-natives) are present in only minor amounts, or have or minor negative impact; and many key plant and animal indicators are present.
C	Occurrence has a number of unfavorable characteristics with respect to the major ecological attributes, natural disturbance regimes. Characteristics include: the landscape context contains natural habitat that is moderately fragmented, with several stressors; the size is small or below, but near the minimum dynamic area; the vegetation structure and composition, soils, and hydrology are altered somewhat outside their natural range of variation; invasives and exotics (non-natives) may be a sizeable minority of the species abundance, or have moderately negative impacts; and many key plant and animal indicators are absent. Some management is needed to maintain or restore[4] these major ecological attributes.
D	Occurrence has severely altered characteristics (but still meets minimum criteria for the type), with respect to the major ecological attributes. Characteristics include: the landscape context contains little natural habitat and is very fragmented; size is very small or well below the minimum dynamic area; the vegetation structure and composition, soils, and hydrology are severely altered well beyond their natural range of variation; invasives or exotics (non-natives) exert a strong negative impact, and most, if not all, key plant and animal indicators are absent. There may be little long-term conservation value without restoration, and such restoration may be difficult or uncertain.[5]

[4] By ecological restoration, we mean "the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed… Restoration attempts to return an ecosystem to its historic trajectory" (SER 2004). As such it may be distinct from rehabilitation, reclamation, creation, mitigation, or ecological engineering, unless these projects have as part of their goal the definition of restoration define above (see SER 2004 for details).

[5] D-ranked types present a number of challenges. First, with respect to classification, a degraded type may bear little resemblance to examples in better condition. Whether a degraded type has "crossed the line" ("transformed" in the words of SER 2004) into a separate, and semi-natural or cultural type is a matter of classification criteria. These criteria specify whether sufficient diagnostic criteria of a type remain, bases on composition, structure, and habitat.

B.1.4. Natural Range Of Variation and Reference Conditions

The ecological integrity criteria (the EO rank specifications) should be based on historical evidence and current status of natural variation, and should include threshold values for both the best conceivable occurrences and those having only fair viability or integrity (see Faber-Langendoen et al. 2008). The criteria should also be developed in a global context. This means that the best occurrence in a particular jurisdiction or geographic area (*e.g.,* ecoregion) may not be highly ranked or even viable. Conversely, from a conservation perspective, if the best existing examples are only ranked C/D, they may still be worthy of protection and management (e.g., California native annual grasslands, Garry Oak woodlands, midwestern Bur Oak savannas).

Reference conditions should characterize the full range of common circumstances –from seemingly ‘pristine,’ or benchmark, sites to highly degraded sites - so that metrics may be developed and applied that adequately characterize that full range. This requires collection of data from a number of locations, ideally from throughout the natural range for the ecological system type. Only through sufficient sampling can the full range of metric values be sufficiently analyzed and interpreted to provide for rigorous and repeatable ecological integrity assessment.

For ecological systems we aim to characterize this A-D scale using the “**expected” natural range of variation** (or **historic range of variation)** concepts, based on based available information. The ecological response to stressors and human alterations can be measured as the degree to which variation in the rank factors and their ecological attributes and indicators/metrics are pushed beyond their natural range of variation. What is natural or historical may be difficult to define for many cases, given our inability to document this range of variation over sufficient spatial and temporal scales and the relative extent of human disturbance over time. However, through reflections on historical data, and analysis of data gathered from with the full range of reference sites, we can often distinguish the effects of intensive human uses and begin to describe an expected natural range of variation for ecological attributes that maintain the occurrence over the long-term.

Too often the characterization of integrity is treated as a static linear function, not unlike the model shown in Figure 2. But such diagrams may be mis-leading with respect to both the ongoing natural, historical processes that shape ecosystems and the human interactions with those systems. It is useful to expand this view by considering how ecology and human culture are “knitted together over time;” that is, both culture and ecology have histories, and consideration of current ecological integrity reflects both histories, without suggesting that they are one and the same (Higgs 2003). What is critical is to ground our ideas of ecological integrity in reference sites; thereby spanning our cultural perspective on integrity with known ecosystem sites in the present, as informed by the past.

Figure 2. Simple schematic showing how ecosystem structure and function may recover over time to either the more original (historical, natural) system or some altered form.

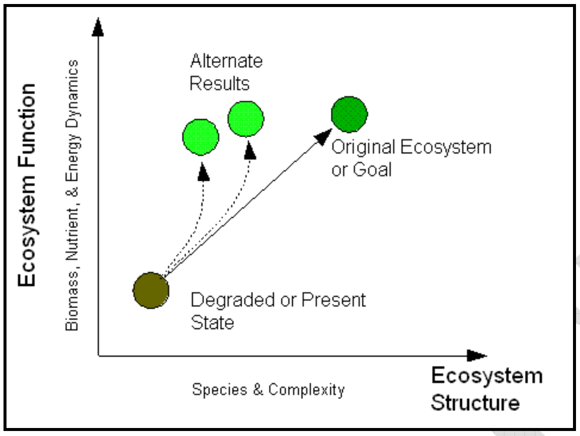
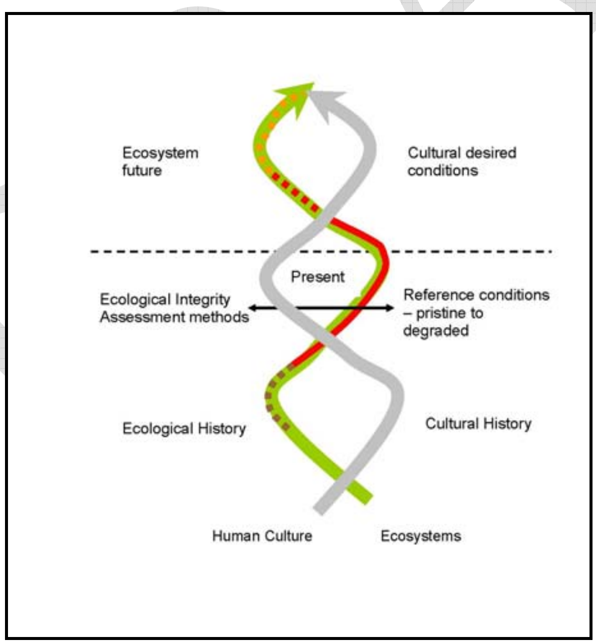


Figure 3. Adapted from Higgs (2003, Fig. 6.2). Permission needed. Red/orange color highlights the increasing changes affecting ecosystems, and the uncertainty of those changes into the future.



Reference sites (or **reference set**) are the sites selected to represent the range of variability that occurs in a type as a result of natural processes and disturbances (e.g., succession, channel migration, fire, erosion, and sedimentation), as well as anthropogenic alteration (e.g., grazing, timber harvest, and clearing) (Klimas et al. 2006). Reference sites serve several purposes. First, they establish a basis for defining what constitutes a characteristic and sustainable level of integrity across the suite of attributes selected for a type. Second, reference sites establish the range and variability of conditions exhibited by assessment variables and provides the data necessary for calibrating assessment variables and models. Finally, they provide a concrete physical representation of ecosystems that can be observed and re-measured as needed (Smith et al. 1995, Klimas et al. 2006).

Reference standard sites are the subset of reference sites that exhibit metric ratings for the type at a level that is characteristic of the least altered (or minimally disturbed) sites in the least altered landscapes (Klimas et al. 2006, Stoddard et al. 2006). As defined above, these reference standards would typically have “A” (excellent) ratings for individual metrics and categories. To complete the full reference set, B, C and D rated sites will be identified and rated as variously degraded versions of A-ranked reference standards. Even where present-day reference standard sites may be hard to identify, one may still be able to make reasonable estimates based on historic data or inferred species-habitat relationships (Brewer and Menzel 2009).

B.2. A 3-Level Approach to Metric Development

B.2.1. Overview of the 3 levels

The selection of metrics to assess ecological integrity can be executed at three levels of intensity depending on the purpose and design of the data collection effort (Brooks et al. 2004, Tiner 2004, US EPA 2006). This ”3-level approach” to assessments, summarized in Table 5, allows the flexibility to develop data for many sites that cannot readily be visited or intensively studied, permits more widespread assessment, while still allowing for detailed monitoring data at selected sites. In the context of a restoration project, the three levels allow for comparison of impacted sites against restored sites in a cost-effective manner.

The 3-level approach is intended to provide increasing accuracy of ecological integrity assessment, recognizing that not all conservation and management decisions need equal levels of accuracy. At the same time, the 3-level approach allows users to choose their assessment based in part on the level of classification (and thereby the specificity of the conceptual model). If one is only classifying to the level of tropical forest versus temperate forest, the use of remote sensing metrics may be sufficient. If one is classifying to montane Red Spruce-Balsam Fir Forest, one has the flexibility to decide to use any of the three levels, depending on the need of the assessment (i.e., there is no presumption that a fine-level of classification requires a fine-level of ecological integrity assessment).

Table 5. Summary of 3-level approach to conducting ecological integrity assessments (adapted from Brooks et al. 2004, USEPA 2006).

Level 1 – Remote Assessment	Level 2 – Rapid Assessment	Level 3 – Intensive Assessment
General description: Remote assessment	**General description:** Rapid field-based assessment	**General description:** Detailed field-based assessment
Evaluates: Condition of individual assessment areas/sites **using:** – metrics within the site that are visible with remote sensing data – Landscape / watershed condition metrics around the site – Limited ground truthing	**Evaluates:** Condition of individual assessment areas/sites **using:** - relatively qualitative or narrative field metrics within the site - remote sensing metrics for landscape context, with limited to expanded ground truthing.	**Evaluates:** Condition of individual assessment areas / sites **using:** - relatively detailed quantitative field metrics - remote sensing / and or field metrics for landscape context, expanded ground truthing / resolution.
Based on: • GIS and remote sensing data • Layers typically include: – Land cover – Land use – Other ecological maps • Stressor metrics (e.g. land use, roads)	**Based on:** • Condition metrics (e.g., hydrologic regime, species composition); and • Stressor metrics (e.g., ditching, road crossings, and pollutant inputs) • Calibration based on reference sites	**Based on:** • Condition metrics that have been calibrated to measure responses of the ecological system to disturbances (e.g., indices of biotic or ecological integrity) • Validation of metrics based on reference sites
Potential uses: • Identifies priority sites • Identifies status and trends of acreages across the landscape • Identifies integrity of ecological types across the landscape • Informs targeted restoration and monitoring	**Potential uses:** • Identifies/confirms priority sites • Informs monitoring of many attributes • Provides baseline data for implementation of restoration or mitigation projects • Supports landscape / watershed planning • Supports assessment of impacted sites based on reference sites	**Potential uses:** • Informs monitoring of a select set of attributes • Identifies status and trends of specific occurrences or indicators • Supports monitoring for restoration, mitigation, and management projects
Example metrics: - Landscape Development Index (integrates stressor impact of various land use types) - Land Use Map - Road Density - Impervious Surface	**Example metrics:** - Landscape Connectivity - Vegetation Structure - Invasive Exotic Plant Species - Forest Floor Condition	**Example metrics:** - Landscape Connectivity - Structural Stage Index - Invasive Exotic Plant Species - Floristic Quality Index (mean C) - Vegetation Index of Biotic Integrity - Soil Calcium:Aluminum Ratio

Level 1 Remote Assessments rely almost entirely on Geographic Information Systems (GIS) and remote sensing data to obtain information about landscape integrity and the distribution and abundance of ecological types in the landscape or watershed (Mack 2006, US EPA 2006, Faber-Langendoen et al. 2008b). Metrics are usually developed from readily available, processed imagery. Limited ground-truthing may be a component of some assessments.[6]

Level 2 Rapid Assessments use relatively rapid field-based metrics that are a combination of qualitative and narrative-based metrics with quantitative or semi-quantitative metrics. Field observations are required for many metrics, and observations will typically require professional expertise and judgment (Fennessey et al. 2007).

Level 3 Intensive Assessments require more rigorous, intensive field-based methods and metrics that provide higher-resolution information on the integrity of occurrences within a site. They often use quantitative, plot-based assessment procedures coupled with a sampling design to provide data for detailed metrics (Barbour et al. 1996, Blocksom et al. 2002). Calculations of indices for assessing Biotic Condition are often used, e.g., Floristic Quality Index, or Vegetation Index of Biotic Integrity ("VIBI") (DeKeyser et al. 2003, Mack 2004, Miller and Wardrop 2006, Miller et al. 2006). The focus of the general Level 3 assessment for biota is on the vegetation, since this is readily observable and measurable, and has been found to be a good indicator of overall condition (Mack 2004), but level 3 assessments typically can include metrics for soils, hydrology, and the surrounding landscape, and can be extended to **birds**, **fish**, **amphibians**, **invertebrates,** and other major ecological attributes of a system (see Fig. 1). These attributes are typically more time-consuming and costly to measure, but their response may differ enough from that of the vegetation that they provide additional valuable information on ecological integrity.

To ensure that the 3-level approach is consistent in how ecological integrity is assessed among levels, a standard framework or conceptual model for choosing metrics is used (as shown in Figure 1). Using this model, a similar set of metrics are chosen across the 3 levels, organized by the standard set of ecological attributes and factors - landscape context, size, condition (vegetation, hydrology, soils).

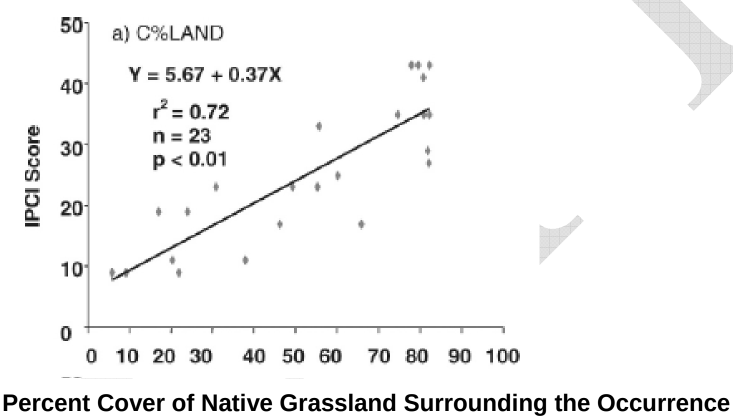
B.2.2. Calibrating the 3-Level Approach

Ideally, information at the three levels of assessment provides relatively consistent information about ecological integrity, with improved interpretations as the level of intensity goes up. To achieve this, the various levels need to be calibrated against each other. For example, sites where a Level 3 index of vegetation or ecological integrity had been measured

[6] It should be pointed out that although remote sensing metrics are usually thought of as "coarser" or less accurate than field-based rapid or intensive metrics, this is not always the case. Some information available from imagery may be very accurate and more intensive than can be gathered in the field. Such information may also be more time-demanding and expensive. For that reason, we also assign a "tier" value to a metric, reflecting its level of precision. Thus it is possible to have a remote sensing indicator (L1) that has 3 metric variants (T1, T2, and T3), reflecting increasing accuracy of the metric. We may expect that for Level 1 assessments a Tier 1 version of the metric is used.

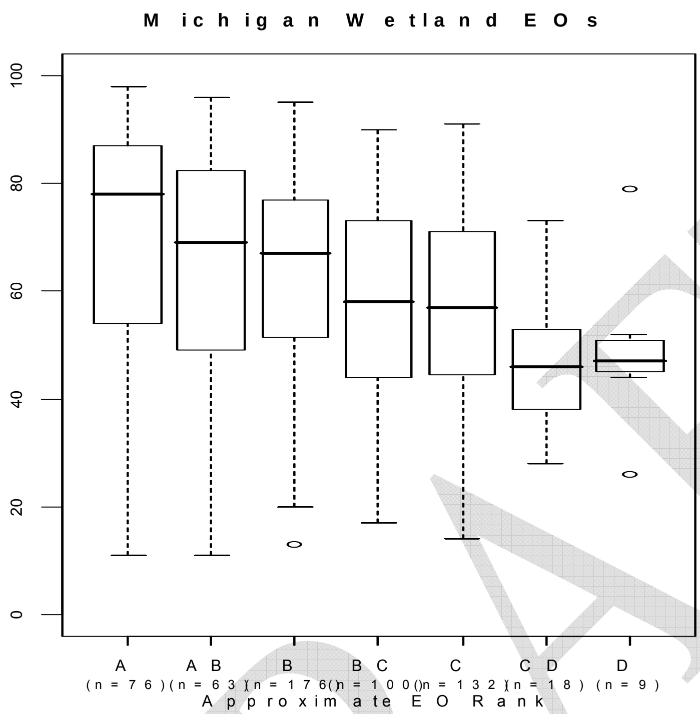
could be used to calibrate the Level 1 remote-sensing based index of integrity (Mack 2006). Mita et al. (2007) provide an example of this approach, where they initially stratified the sites using a landscape stressor model that combined a suite of land use metrics to assess wetland integrity. They then sampled a range of sites across the gradient of stressors, and developed a level 3 index of plant community integrity. They then compared the level 3 index against the original set of combined land use metrics as well as individual land use metrics. Although they originally tried using a suite of stressors in their landscape stressor model, they found that a single metric "percent cover of native grassland in the surrounding landscape" was the best predictor of the level 3 measure of biological integrity.

Figure 5. Effectiveness of Level 1 (remote sensing) Metrics in Predicting Level 3 Integrity
IPCI = Index of Plant Community Integrity (from Mita et al. 2007).



We have begun to test our landscape condition model against sites where indices of ecological integrity are available for all wetland in a state through a rapid field-based assessment conducted by state Heritage Program ecologists (EO ranks) (Fig 6). We compared the index of ecological integrity as estimated through a level 2 rapid field assesment (Heritage Program EO rank based on integrating ratings for landscape context, size, and condition) with that predicted by a level 1 landscape condition model. Data are still under review but we found a reasonable trend, where the highest ranked EOs were found in the landscapes with the best condition (i.e. least stressors). There is substantial variation, however, suggesting that knowledge of stressors alone is insufficient to predict ecological integrity at finer scales of assessment. It may also be that looking at individual wetland types and refining the model for those types could improve the correlation.

Fig. 6. Comparison of the index of ecological integrity as estimated through a level 2 rapid field assesment (Heritage Program EO rank based on integrating ratings for landscape context, size, and condition) with that predicted by a level 1 landscape condition model. EOs = element occurrences, which are polygon-delineated locations of a wetland type at a site. The Landscape model scale is scaled continuously from 0 (degraded) to 100 (pristine) Box and whisker plots. Note, date are still under review.



B.2.3. The interrelation of classification and choice of metrics

The success of developing indicators of ecological integrity depends in part on an understanding of the structure, composition, and processes that differ across the wide variety of ecosystems. As noted above, ecological classification and regionalization of types can be helpful tools in categorizing this variety. They help managers to better cope with natural variability within and among types, so that differences between occurrences with good integrity and poor integrity can be more clearly recognized.

But ecological integrity is not a simple, definable concept. It has **multiple ecological attributes**, including vegetation, soils, hydrology, and landscape context (as well as birds, amphibians, etc.) that can be addressed at **multiple scales**. Ecologists may be able to get a coarse understanding of ecological integrity using some broad-scale metrics that address only some of the relevant attributes (e.g., the remote-sensing based metrics that comprise many “Level 1” assessments), or they may conduct a quick, ground based survey based on rapid field metrics that survey all major attributes (Level 2 assessments), or intensive, quantitative metrics, that may choose to emphasize a few attributes as indicators of the status of other attributes ("Level 3 assessments"). A few examples may make this clear:

<u>Examples of metrics that may not require customization by type or ecoregion.</u>

1. "Percent cover of invasive exotic plants." (e.g., Faber-Langendoen et al. 2008a)
2. "Landscape Connectivity." (e.g., McIntyre and Hobb 1999).

These metrics can be applied to any natural ecosystem. The reference standard values would be the same regardless of the type. (<1% exotics, >90% connectivity)

<u>Examples of metrics that typically do require customization by type or ecoregion.</u>

1. "Floristic Quality Index" (FQI) or "Coefficient of Conservatism" (CC) (e.g., Lopez and Fennessy 2002).

The floristic quality index is based on an assessment of how "conservative" or sensitive a species is to human disturbances. But these sensitivities can vary across regions because not all species behave similarly across their range. For example, e.g., *Acer negundo* (box elder) is exotic in NY, but native in Arkansas; *Dasiphora fructicosa var. floribunda* (shrubby cinquefoil) is a fen indicator in the northeast and Midwest U.S., but is a dry-mesic upland species in parts of the Northwest Great Plains. Thus, although the overall form of the metric may be the same across the country, it will require many variants, by state or ecoregion.

2. Hydrologic Connectivity (e.g., Collins et al. 2006)

This metric varies in part by HGM class. For example, organic flats such as bogs are defined by lack of connectivity, whereas riverine floodplain forests depend on it.

3. Vegetation Structure (e.g., Faber-Langendoen et al. 2008b)

This metric varies by Cowardin class / USNVC formation, not so much by HGM class. Within the same HGM Depression type, the forested swamps need a different form of the vegetation structure metric than do the herbaceous marsh or aquatic vegetation.

Thus a critical issue that hovers over the methodology is that the choice of metric partly determines the level of classification or ecoregional framework needed for the assessment, and vice versa. Still, we can proceed under the following assumption: **in order to develop sound metrics, we need to pay attention to both the level of metric resolution (from level 1 to level 3) and the level of classification that is desired or needed in order to accurately develop the metric**. In this way, we can ensure that metrics are chosen will be able to accurately describe the expected range of reference conditions for various ecosystem types.

B.2.4. Additional wrinkles in choice of metrics

Two additional issues affect how metrics are chosen for reference sites. First, the geographic/jurisdictional scale of the assessment. National assessments span a much greater ecological extent, and typically cannot conduct the level of intensity of sampling or survey that a state or regional assessment can conduct. State or local assessments may be conducted state-wide or on individual state or national forest or parks, preserves or local landscapes. Here the intensity of sampling may be greater, and repeat visits may be more feasible. In turn, the choice of metrics at this level are affected by the degree to which those assessments want to link to the national study. Thus, when identifying a set of reference sites, we may need an approach that is guided by expectations at multiple scales. Having standardized, multi-level ecosystem types and metrics across projects will greatly facilitate implementation of EIAs.

Second, the objectives of the assessment are affected by the relative need for monitoring. EIAs completed as a **one time assessment** may not need the same kind of metrics compared to those as those that involve **repeat assessments** (where the goal is primarily on change in the status of integrity, not so much trend analysis, and **monitoring**, where trends in the values of the various metrics as well as change in status are important.

For NatureServe and the Network, when working with conservation partners who maintain sites for their biodiversity conservation value, our primary interest in EIAs is to agree on a set of ecosystem types, whose ecological integrity is assessed consistently, at multiple levels, across a suite of sites, with a primary goal of conducting repeat assessments to ensure that ecological integrity is being maintained or improved.

B.3. Metric Selection and Rating

B.3.1. Metric Selection

Using our conceptual model as a guide, we want to identify a core set of metrics that best distinguish a highly impacted, degraded or depauperate state from a relatively unimpaired, intact and functioning state, based on assessing the major ecological attributes (Fig. 1). Metrics may be based on characteristics that typify a particular ecosystem or attributes that change predictably in response to anthropogenic stress. The suite of metrics selected should be comprehensive enough to incorporate composition, structure and function of an ecosystem across a range of spatial scales. Ideally, indicators of the magnitude of key stressors acting upon the system will be included to increase understanding of relationships between stressors and effects (Tierney et al. 2009).

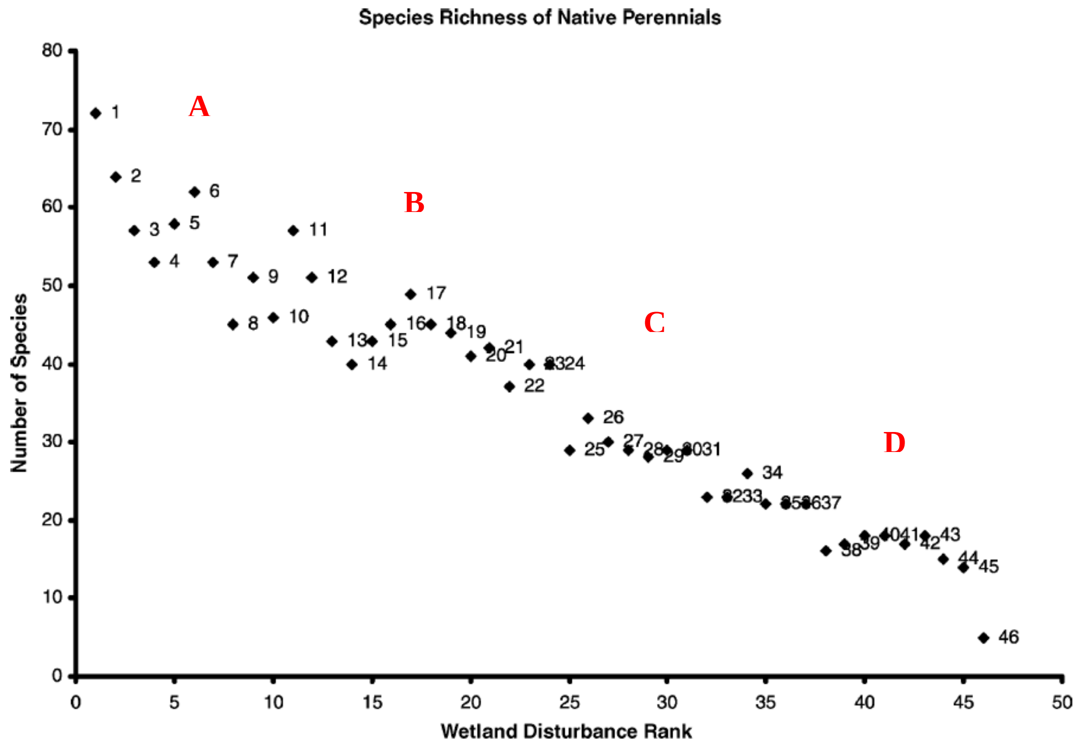
Not all measures of various characteristics in a ecosystem qualify as ecological integrity metrics. For example, one can measure the total density of woody stems in a forest or count the density of tillers in a grassland, but by themselves they may indicate little about integrity. But if one can link the density of dead standing snags to ecological processes such as natural disturbance regimes or the population density of an key animal species, then such measures become metrics - measurable expressions of an aspect of ecological integrity. For further guidance on metric selection see Shriver et al. (2004) and Faber-Langendoen et al. (2006).

Metrics may be identified using a variety of expert-driven processes and through a series of data-driven calibration tests. NatureServe engages ecologists from across the Network of Natural Heritage Programs and from other agencies and organizations to review and test the metrics. In the last ten years, there has been a great deal of research to identify practical suites of metrics that address the different aspects of ecosystem structure, composition, and function, and our own methodology has evolved to incorporate those findings. For example, for level 2 (rapid field) metrics for wetlands, there are a variety of existing remote and rapid assessments manuals, particularly that of the California Rapid Assessment Manual (Collins et al. 2006, 2007), the Ohio Rapid Assessment Manual (Mack 2001), and these have been reviewed when developing NatureServe's wetland assessment methods (Faber-Langendoen et al. 2008a). For level 3, for forests, the National Park Service Northeast Temperate Network developed a suite of metrics (Tierney et al. 2009). The Montreal Protocol also includes a number of metrics (REFS), a number of which are available through the U.S. Forest Service Forest Inventory and Analysis Program (REFS)). In grasslands, deserts, and other rangelands there have been other efforts (REFS).

B.3.2. Development of Metric Ratings

To ensure the merits of a particular metric, we need to consider whether it can be rated in a way that is informative about the overall integrity or sustainability of the site (this is sometimes described as the metrics showing a "stressor-dose response" to changes in stressor levels). Ultimately, one can conduct field tests, where the metrics are measured across a range of sites that span the gradient of stressor or disturbance levels. An example of how the merits of a particular metric can be tested is provided by DeKeyser et al. (2003), who showed how native perennial species richness in prairie potholes declined in a predictable manner as disturbance increased (Fig. 7). The response of the metrics can be summarized either as a continuous function or through a series of categorical ratings (A through D).

Figure 7. Example of the change in a metric over a disturbance gradient, showing how it declines more-or-less continuously to increasingly levels of disturbance.
Adapted from E.S. DeKeyser et al. Ecological Indicators 3 (2003) 119–133



At the level of individual metrics, ratings may range from a simple pass/fail to a six point A – F scale. The more ratings a metric has, the more sensitive it is judged to be in indicating degradation or restoration. For example, in intact, pristine ecosystems, the relative total cover of exotics are essentially zero. Even small percentage changes of 1-2% are considered significant indicators of decline in condition. Thus the metric is sensitive enough to be divided into 5 ratings, when applied as a Level 2, field-based metric (see Table 6).

Table 6. Example of a Metric with Ratings

The metric “Relative Total Cover of Native Plant Species” can be used for Level 2 rapid field assessments, where estimates of cover would be made rapidly over the site. It could also be refined to be a Level 3 metric, if vegetation plots were laid to carefully estimate cover. Rarely, it could be used as a Level 1 metric, where invasive exotics are visible from imagery, but the rating scheme could be simplified, combining A-C, then D, then E.

CONDITION **Vegetation**	
Metric:	Relative Total Cover of Native Plant Species
Definition:	Percent cover of the plant species that are native, relative to total cover (sum by species)
Metric Ratings	**Metric Criteria**
A = Excellent	>99% cover of native plant species
B = Good	97-99% cover of native plant species
C = Fair	90-96% cover of native plant species
D = Poor	50-89% cover of native plant species
E = Very Poor	<50% cover of native plant species

Our documentation of the metrics is similar to that of some HGM assessments (e.g., Hall et al. 2003) and to the Standard Operating Procedures by NPS Vital Signs Program (Oakely et al. 2003).

C. IMPLEMENTING METRIC DEVELOPMENT USING THE 3-LEVEL APPROACH

It is no small task to undertake a comprehensive approach to EIA development. Here, we outline how we plan to proceed to develop EIAs for all terrestrial (upland and wetland) ecosystems using a 3-level approach. Marine and freshwater aquatic ecosystems will be treated separately.

Although the three levels are integrated, we develop each level as a stand-alone method for asessing ecological integrity. **When conducting an ecological integrity assessment, one need only complete a single level that is appropriate to the study at hand.** Typically only one level may be needed, desirable, or cost effective. But for this reason it is very important that each level provide a comparable approach to assessing integrity, else the ratings and ranks will not achieve comparable information if multiple levels are used. It is also possible to use the three levels together. One might first assign a Level 1 rating or rank to all occurrences, then choose among them to assign a Level 2 rank, and finally, focus on a few with a Level 3 assessment. The process should lead to an increasing accuracy of assessment. Where information is available for all three levels across multiple sites, it is desirable to calibrate the levels, to ensure that there is an increase in accuracy of the assessment as one goes from Level 1 to 3 (See Section B.2.1).

Although metrics are typically associated with a given level, a certain amount of mixing can occur. For example, a remote sensing assessment may include some ground-truthing that permits a limited amount of rapid field survey. Or a level 2 rapid field assessment could include one or more vegetation plots to permit calculation of a level 3 metric (species richness or floristic quality). **Allowing the same occurrence to be assessed at multiple levels will require that the database records for a site or an occurrence (EO Record in Heritage methodology) be able to store information at each level separately.**

Finally, the three-level approach is focused on a point or patch/polygon scale. It is possible to combine it with various landscape models to provide a broad-scale characterization of integrity at the landscape or watershed scale. Because these landscape characterization models can provide much of the data needed to conduct a level 1 (remote sensing) assessment, we begin with these models.

C.1. Integrating Ecosystem Classification to Level of Assessment

To develop sound metrics, we need to pay attention to both the level of metric resolution (from level 1 to level 3) and the level of classification that is desired or needed in order to accurately develop the metric (see Section B.2.3). By doing so, we can make our methodology both practical and flexible to a range of assessment types that range from broad to local and from extensive to intensive. We use both the level of assessment and level of classification to guide development of Ecological Integrity Assessments (Table 7).

For Level 1 EIAs, we provide a single general method for all natural ecosystems. Although this may seem crude, we feel it is important that some general method be available at the outset in order to effectively implement the overall methodology. Naturally, it better be pretty good, or it will be counter-productive. It is described in detail in Section C.2. below.

For Level 2 assessments, we provide core metric lists at the level of formation, but provide variants based on component macrogroups, groups or Systems, or more rarely associations and natural communities. For Level 3 assessments we will rely more strongly on macrogroups, groups or Systems and their component associations and natural communities to develop the metrics (Table 7).

The purpose of intersecting the classification with that of EIA methods is that as the level of assessment intensifies, we may find (but not always) that a greater level of ecosystem classification detail is needed (see Section B.2.3). For example, when assessing coarse woody debris (a Level 2 or Level 3 metric), we may expect some fundamental differences between tropical moist forests and temperate forests (a formation level distinction), but if we fine tune the variation in this metric, we may also need to classify ecosystems more finely at a Group or Ecological System scale, such that we separate temperate Red Spruce-Fir Forest, Northern Hardwood & Hemlock Forest, and Longleaf Pine Woodland, etc. Finally, we may find that, if measured precisely, coarse woody debris differs between Beech-Maple Forest and Hemlock-Hardwood Forest.

Not all metrics for a given assessment vary by classification scale. The examples given in Section B.2.3. are worth repeating; namely that metric such as “Relative Total Cover of Native Plant Species,” or “Landscape Connectivity” may not need to vary much by classification type. This also simplified the task of EIA development.

Table 7. Summary of how the NatureServe methodology uses both level of assessment and level of classification to guide development of Ecological Integrity Assessments. For various levels of assessment, we show the level and types of classification units needed to develop an EIA. In the far right column is shown the number of EIAs needed for a given Assessmetn Level.

ASSES SMENT	**CLASS-IFICATION**							**EIAs needed**
L1			**All Natural**		**Ecosystems**			1 **(complete)**
	FORMA-TION CLASS	1. Forest & Woodland	2. Low Shrub & Grassland	3. Semi-Desert	4. Polar & High Montane Vegetation	Aquatic & Other Wetland Vegetation	Nonvascular & Other Sparse Vascular Rock Vegetation	6
L2	FORMA-TION	1. Tropical Lowland Rain Forest 2. Tropical Dry Forest. **3. Temperate & Boreal Forest***	1. Tropical Shrubland, Grassland, & Savanna* **2. Temperate Shrubland, Grassland, & Savanna*** 3. Mediterranean Scrub 4. Boreal Grassland, Meadow & Shrubland 5. Coastal Scrub and Herb	**1. Warm Semi-Desert** **2. Cool Semi-Desert**	1. Tundra 2. Temperate Alpine 3. Tropical High Montane (Alpine)	**1. Floodplain & Swamp Forest*** **2. Mangrove** **3. Bog & Fen*** **4. Freshwater Marsh*** **5. Salt Marsh** **6. Tundra Wetland** 7. Freshwater Aquatic Vegetation 8. Saltwater Aquatic Vegetation	1. Tropical Cliff etc. 2. Temperate, Mediterranean, & Boreal Cliff, etc. 3. Semi-Desert Cliff etc. 4. Polar & High Montane Cliff etc.	24+ (**10 completed or in review**)
L3 (L2)	MACRO-GROUP / GROUP AND System				L2 Metrics often need variants,	based on Macrogroups. Groups or Systems		100s (variants of the above)
L3 (L2)	ASSOCIA-TION / Natural Community				Rely on Network	Of Heritage Program collaboration		1000s (variants of the above)
		*specific formations for Cool Temperate, Warm Temperate, and Boreal	*specific formations for lowland, montane, and coastal			* specific formations for Tropical, Temperate, and Boreal		

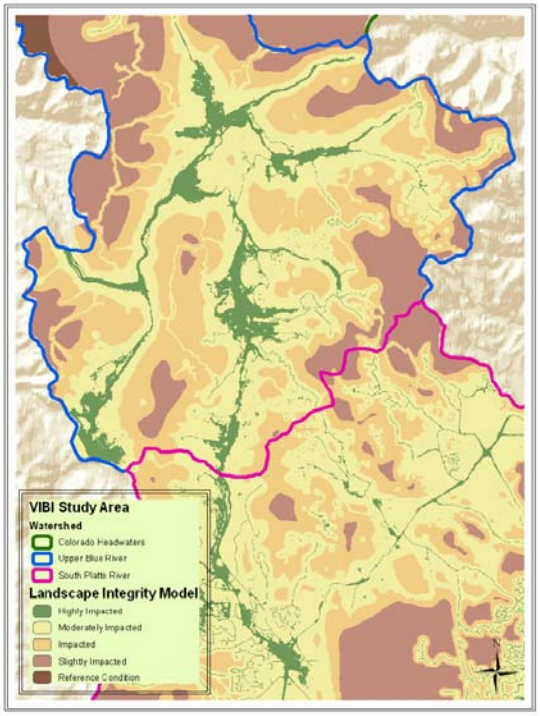
C.2. Level 1 Assessment

Level 1 Assessments are based primarily on metrics derived from remote sensing imagery. The Level 1 integrity ranks are often used as a means of prioritizing sites for field visits, where a Level 2 or Level 3 assessment is completed. However, Level 1 ranks can also be used as a measure of integrity or to assign an EO rank whenever a field visit cannot be completed or is very brief. Because the purpose is the same for all three levels of assessment (to establish an ecological integrity or EO rank) it is important that level 1 assessment use the same kinds of metrics and major attributes as used at levels 2 and 3. As a first step in developing a level 1 assessment, it can be helpful to develop a landscape or watershed characterization of condition, based on a landscape condition model. We outline this approach first and then show how it can be used to implement a level 1 assessment.

C.2.1. Landscape Condition Model

A first helpful step in assessing the ecological integrity of specific occurrences is to characterize the condition of the overall landscape or watershed that an occurrence is found in. Typically, this is done indirectly by assessing the stressors on the landscape [and maybe the model should be called a Landscape Stressor Model!]. For example, NatureServe has developed a Landscape Condition Model (LCM, Tuffly and Comer 2005, Comer et al. in prep). The model is similar to the Landscape Development Index used by Mack (2006) and the anthropogenic stress model of Danz et al. (2009). The algorithm integrates various land use GIS layers (roads, land cover, water diversions, groundwater wells, dams, mines, etc.) at a 30-90 m or 1 km pixel scale. These layers are the basis for various metrics, which are based on stressors. The metrics are weighted according to their perceived impact on ecological integrity, into a distance-based, decay function to determine what effect these stressors have on landscape integrity. The result is that each grid-cell (30 m or more) is assigned a stressor "score". The product is a landscape or watershed map depicting areas according to their potential "integrity." We can segment the index into four rank classes, from Excellent (slightly impacted) to Poor (highly impacted) (Figure 8). This landscape model is valuable in its own right for landscape scale planning, site selection etc.

Figure 8. Landscape Condition Model integrateing stressors within a watershed (from Rocchio 2007).



C.2.2. Level 1 Metrics and Ratings

A comprehensive set of Level 1 metrics and protocols have been developed for all natural ecosystems (Faber-Langendoen et al 2008b). Table 8 provides the list. Essentially, Level 1 is a comprehensive generic EIA approach that is applicable to all natural ecosystems. One metric – vegetation structure - has variants based on the formation class that a polygon or occurrence may have. One major ecological attribute and its associated metrics may be added if the polygon or occurrence is identified as a wetland. Other variants may be added as further testing is conducted.

A Level 1 assessment is based primarily on metrics derived from remote sensing imagery, including those that may have been used to develop a landscape condition or stressor model (see section C.2.1. above). We can take the imagery and select and organize metrics by our conceptual model (Fig. 1s). Remote sensing metrics are emphasized, but it may be possible to conduct some ground-truthing to both validate some of these metrics or even add some limited rapid field metrics. The assessment includes landscape context, size and condition metrics. For each metric, a rating is developed and scored, from excellent (A) to poor (D), usually in a 4-category scale, but sometimes 3 or 5. The background, methods, and rationale for each metric are described in a protocols document (Faber-Langendoen et al. 2008b). After each metric is rated, then various metric ratings are aggregated together into ratings for the major attributes and rank factors, and into an overall index of ecological integrity.

Table 8. A draft ecological integrity table for a level 1 assessment.

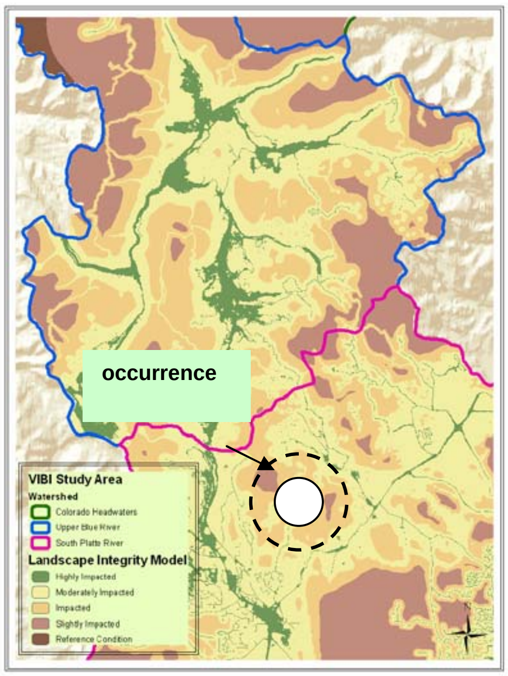
The table is applicable to all natural ecosystems. Stressor checklist information is not used directly to assess condition, but is considered informative.

Rank Factor	Major Ecological Attribute	Indicator/Metric
LANDSCAPE CONTEXT	**Landscape Context**	Landscape Connectivity
		Surrounding Land Use Index [or Landscape Condition Model Index]
		Landscape Context Stressors Checklist
		Buffer (opt., for wetlands)
SIZE	**Size**	Patch Size
		Patch Size Condition
CONDITION	**Vegetation**	Vegetation Structure (varies by NVC class)
		Vegetation Composition
		Relative Percent Cover of Native Plant Species (opt.)
		Invasive Exotic Plants
		Vegetation Stressors Checklist
	Soils	Soil/Substrate Condition
		On-Site Land Use Index
		Soil /Substrate Stressors Checklist
	Hydrology (opt) wetlands	Hydrologic Alterations (non-riparian)
		Floodplain Interactions (riparian)
		Upstream Surface Water Retention (riparian)
		Upstream/On-Site Water Diversion (riparian)
		Hydrology Stressors Checklist

Testing of level 1 metrics will be done by checking to see how well Level 1 metrics predict Level 2 or Level 3 ranks for specific association or system occurrences (see "Calibration" section below).

An example of how to implement a Level 1 assessment is as follows: Locations are chosen within the watershed or landscape. These locations are any or all examples of an ecosystem type that is of interest, e.g., all or some forest stands, or wetlands, identified to level of ecosystem classification. Points or polygons are established for each of these locations, and these are overlain on the Landscape Condition Model. A landscape context area is defined around the occurrence (Fig. 9). The landscape condition model provides the data for the "landscape condition model index" metric, based on the average score of the pixels within the landscape context. Connectivity and Size can be readily assessed. The same model can be used to produce the data for the "On-Site Land Use Index" metric. Other remote sensing data will be needed to estimate the other metrics. Together these metrics provide a simple means of characterizing the integrity (or EO rank) of the occurrence.

Figure 9. Demonstration of Level 1 Assessment based on a Landscape Condition Model. Values for landscape context metrics and condition metrics for an occurrence can be derived from the model.



C.3. Level 2 Assessment

Level 2 metrics are the core metrics that are used for relatively rapid (~2 hours per occurrence) site visits. Assessments using level 2 metrics are often referred to as "rapid assessment methods" (Fennessy et al. 2007), and are most similar to typical heritage ecology evaluations. Rapid assessment methods are becoming widely available for wetlands, and are being put into use by many state wetland programs (Fennessy et al. 2007). Typically three to five metrics are identified for each of the main rank factors. Here we extend the approach to all terrestrial (upland and wetland) ecosystems.

A comprehensive set of metrics and ratings are being developed for all Level 2 metrics at the IVC Formation level (e.g., Temperate Bog & Fen, Cool Temperate Forest, Temperate Grassland & Shrubland), with variants provided for some metrics based on Macrogroups or Systems, or in the case of wetlands, by Hydrogeomorphic class. Protocols for evaluating Level 2 metrics in the field are being developed, and are curently available for all temperate wetland formations (Faber-Langendoen 2008a), and for forests and woodlands (Faber-

Langendoen et al. 2009). Draft versions are underway for temperate grasslands (Kittel et al. in prep), cool semi-deserts and warm semi-deserts (Muldavin, Schulz and others in prep).

The greatest effort to date has been for wetlands where metrics now exist for all wetland types (Table 9, from Faber-Langendoen et al. 2008). Extended details are available in Faber-Langendoen et al. (2008a). See also Rocchio (2007).

Metrics and their variants are intended to be comprehensive across the nation, with specificity to NVC formation as needed. The metrics have not yet been widely calibrated, but various tests are underway. Further testing is also needed to determine if greater specificity is needed in the wetland classes in order to be able to consistently rate the metrics. (i.e. do we need to increase our classification level from NVC Formation to Macrogroup or Ecological Systems (see Table 7).

Table 9. Example of an ecological integrity table, for wetland ecosystems. The checklists provide additional information on stressors to the wetland site or occurrence. Details are provided in Faber-Langendoen et al. (2008a).

Rank Factor	Major Ecological Attribute	Indicator
LANDSCAPE CONTEXT	Landscape Structure	Landscape Connectivity
		Buffer Index
		Surrounding Land Use Index
	Landscape Stressors	Landscape Stressors Checklist
SIZE	Size	Patch Size Condition*
		Patch Size
CONDITION	Vegetation (Biota)	Vegetation Structure
		Organic Matter Accumulation
		Vegetation Composition
		Relative Total Cover of Native Plant Species
	Vegetation (Biota) Stressors	Vegetation (Biota) Stressors Checklist
	Hydrology	Water Source
		Hydroperiod
		Hydrologic Connectivity
	Hydrology Stressors	Hydrology Stressors Checklist
	Soils (Physicochemical)	Physical Patch Types
		Water Quality
		Soil Surface Condition
	Soils (Physicochemical) Stressors	Soils (Physicochemical) Stressors Checklist

*optional metric

C.4. Level 3 Assessment

C.4.1. Introduction

Level 3 metrics are intensive metrics that typically contain a more intensive sampling design, often requiring a ½ day or more to complete. The Level 3 assessment can take several directions:

a) intensify the vegetation, hydrology and physico-chemical metrics collected at level 2, e.g., rely on monitoring wells to assess hydroperiod),
b) rely on detailed vegetation plots to characterize vegetation composition, perhaps using a floristic quality assessment (FQA) index or a Vegetation Indiex of Biotic Integrity VIBI), and/or
c) consider selecting other independent biotic metrics, such as amphibians, birds, or fish to determine how their response compares to that of vegetation, hydrology, and physico-chemical factors. The choice of metrics may depend on the specific monitoring assessment needs of a particular project.

It will be challenging to develope a general set of Level 3 metrics across the nation for any major set of ecosystems, particularly because a greater level of ecosystem type informaiton is needed (Table 7). Level 3 metrics are often more sensitive to regional variation and differences caused by finer-scale differences among ecosystem types. Level 3 assessments are also time-consuming, costly and may required extended commitments. They are most valuable where it is important to assess in detail the status and trends of particularly important sites.

Nonetheless there are increasing number of efforts to create cost-effective and ecologically realistic level 3 assessments. For wetlands, a number of field studies have been conducted in which a Vegetation Index of Biotic Integrity (VIBI) was developed (e.g., DeKeyser et al. 2003, Mack 2004, Miller et al. 2006, Rocchio 2007). A VIBI can be developed that either serves as an indicator of all ecological attributes, or, if other metrics are developed for hydrology and soils, it serves as an indicator of the biotic attribute of the wetland. In addition, other biotic components, such as amphibians or macroinvertebrates, could be measured separately. For wetland and for uplands a variety of active programs are described below (Section C.4.2).

C.4.2. Examples of Level 3 Assessments

National Park Service: Northeast Temperate Network

See Tierney et al. (2009). [More information will be provided to describe this program]

U.S. Forest Service FIA program

For upland forests, a variety of consultations are under way to determine how data gathered by the U.S. Forest Service Forest Inventory and Analysis (FIA) program can be used to generate data that inform metrics for ecological integrity. [More information will be provided to describe this program. See Chip Scott, Randy Morin]

National Wetland Condition Assessment.

See Scozzafava et al. [More information will be provided to describe this program]

Michigan – Indiana Wetland Assesment

[More information will be provided to describe this program]

C.5. Hybrid Assesesments

It should be noted that there is no necessary reason to keep the levels strictly separate. If the goal is simply to estimate ecological integrity as accurately as possible, given limitation on time and resources, it maybe that landscape context and size are measured using level 1 (tier 1) metrics, soils and hydrology using level 2 metrics, and vegetation using level 3 metrics. This again highlights the benefits of developing the levels of assessmetn in comparable ways, to facilitate working between levels.

C.5.1. FIA Forest monitoring and Hybrid Assessment

The USFS FIA program is an interesting hybrid of Level 2 and Level 3 Ecological Integrity assessment metrics. With respect to our overall set of criteria, FIA is a level 3 assessment. It has a sophisticated sample design, requires experienced field crews to collect intensive, plot-based metrics. At the same time, only tree data are collected for the vast majority of plots. Thus there are some metrics on vegetation structure that can be measured at Level 3, but other metrics, such as percent invasives, can only be approximated buecause only tree species composition is recorded. Data on soils and hydrology are lacking and estimates of landscape context are typically not collected as part of the assessment, but can be estimated from remote sensing imagery, using level 1 or level 2 metrics.

See Cutko (200?) for an adaption of FIA protocols that are more directly equivalent to a level 3 ecological integrity assessment, where shrub and herb species are also recorded.

D. Ecological Integrity Scorecard

Andreasen et al. (2001) outline six characteristics that a practical index of ecological integrity should have:

- Multi-scaled
- Grounded in natural history

- Relevant and helpful (to the public and decision-makers, not just scientists)
- Flexible
- Measurable
- Comprehensive (for composition, structure and function).

Our propoped index of ecological integrity is based on these suite of characteristics. Ratings for each metric at mulitple levels provides us with a flexible, multi-scaled set of measurable metrics that are firmly anchored in the natural history of ecosystem types. By using our conceptual model as a framework, we ensure that the metrics are comprehensive and helpful to a wide audience. We summarize our knowledge of ecological integrity using a comprehensive tabular format, ultimately leading to a scorecard rating of "A" (excellent), "B" (good), "C" (fair), and "D" ("poor") (see also Table 2).

At root, presentation of the metrics in a tabular format organized by the conceptual model is already very informative (see Tierney et al. 2009). Various means of showing trend over time can be added to each metric.

It can also be desirable to aggregate the metric ratings. A number of approaches are available, each with a variety of strengths and weaknesses (Faber-Langendoen et al. 2007). We use a simple **non-interaction point-based approach**, where we treat each metric independently. We first structure the scorecard using the conceptual model (see Table 10). Each metric within a major ecological attribute is assigned a weight, based on its perceived importance. Ratings for each metric are presented, along with conversion to a point value for that rating (A = 5 points, B = 4, C=3, D=1). Then the points are multiplied by the weight to get a score for the metric (e.g. the metric "Organic Matter Accumulation" is weighted 0.5, its rating is C=3 points, therefore its score is 1.5). The scores (weighted points) for all metrics within a major attribute are summed and divided by the sum of the weights to get an attribute score. Each major attribute is weighted equally (this can be changed). The attribute scores are summed and divided by the total number of attributes to get an overall score, which is converted to an Index of Ecological Integrity. If desired, Vegetation, Soils and Hydrology can be combined separately into a Condition score before producing an overall index rating. A fully worked example is shown in Table 10. The point-based approach is consistent with that of many IBI scoring methods (e.g. Karr and Chu 1999).

Table 10. Summary of scores and ranks for metrics, factors, and the overall ecological integrity for a Level 2 Rapid Field-based Assessment. Vegetation, Hydrology and Soils are major attributes within the Condition rank factor.

MAJOR ATTRIBUTES **Metric**	**Assigned Metric Rating**	**Assigned Metric Points**	**Weight (W)**	**Metric Score (M)**	**Rank Factor Score (M/W)**	**Rank Factor Rank**	**Ecological Integrity Score**	**Ecological Integrity Rank (EO rank)**
LANDSCAPE CONTEXT					4.3	B		
Landscape Connectivity	A	5	1	5				
Buffer Index	B	4	1	4				
Surrounding Land Use	B	4	1	4				
			∑=3	∑=13				
SIZE					4.3	B		
Relative Size	A	5	0.5	2.5				
Absolute Size	B	4	1	4				
			∑=1.5	∑=6.5				
VEGETATION (BIOTA)					3.6	C		
Vegetation Structure	C	3	1	3				
Organic Matter Accumulation	C	3	0.5	1.5				
Vegetation Composition	B	4	1	4				
Relative Total Cover of Native Plant Species	B	4	1	4				
			∑=3.5	∑=12.5				
HYDROLOGY					4.0	B		
Water Source	C	3	1	3				
Hydroperiod	B	4	1	4				
Hydrologic Connectivity	A	5	1	5				
			∑=3	∑=12				
SOILS (PHYSICOCHEMISTRY)					4.0	B		
Physical Patch Types	B	4	0.5	2				
Water Quality	B	4	1	4				
Soil Surface Condition	B	4	1	4				
			∑=2.5	∑=10				
					∑=20.5			
RATING **A**=4.5-5.0, **B** = 3.5-4.4, **C**=2.5-3.4, **D**=1.0-2.4							4.1	B

E. Adapting the Method over Time

Our efforts to assess ecological integrity are approximations of our current understanding of any ecosystem. In reality, ecosystems are far too complex to be fully represented by a suite of metrics and attributes. Moreover, our metrics, indices and scorecards must be flexible enough to allow change over time as our knowledge grows.   What is important is that we present as clearly as we can how we are conducting our assessments, so that we foster communication and understanding among people with different backgrounds, goals, and points of view.

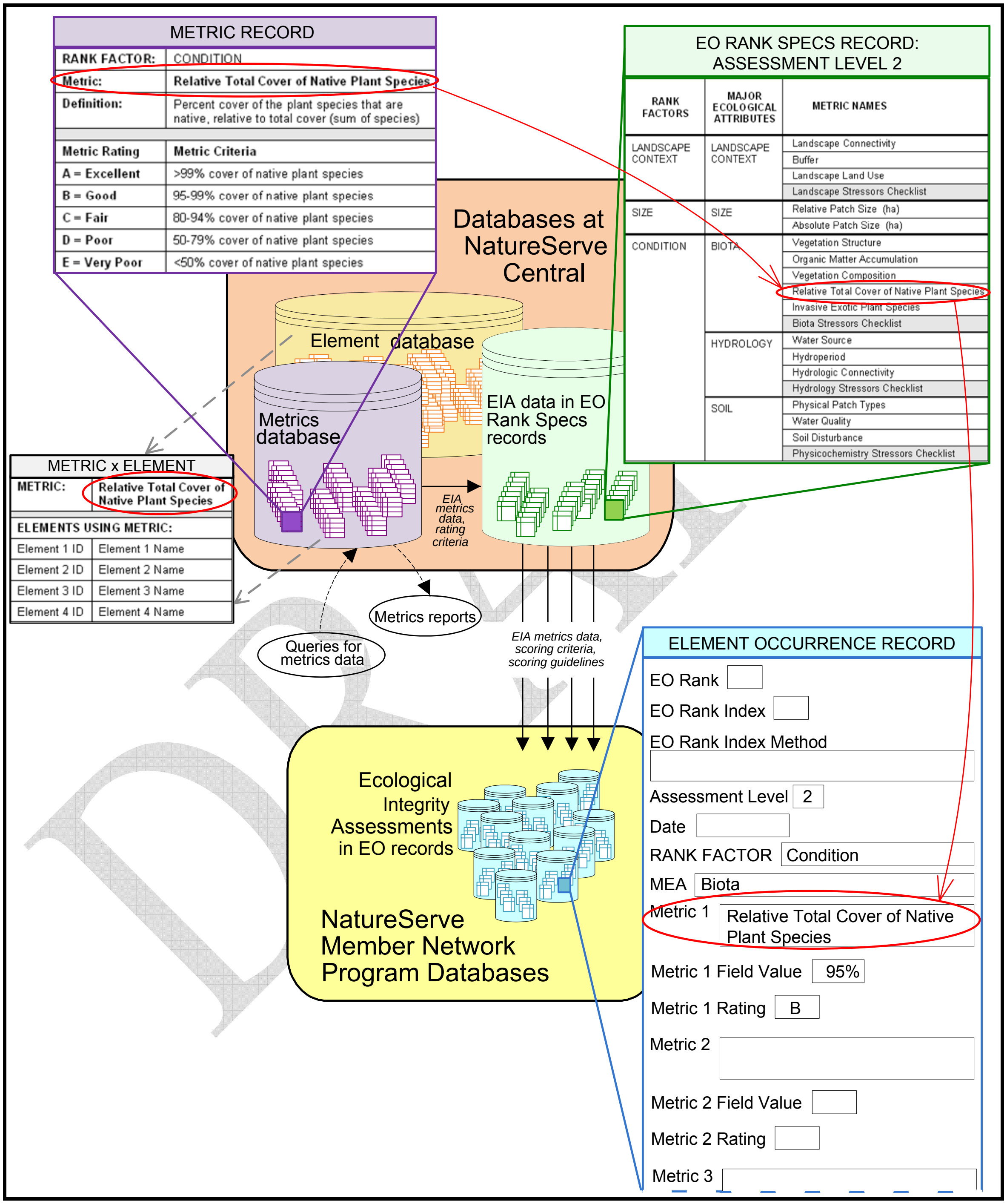
NatureServe is upgrading its Biotic database to manage and store the ecological assessments, including the component metrics, and will incorporate improved versions of metrics as they are field-tested and validated (Fig 10). Thet database includes several important features:

d) a metrics database that describes the metrics and protocols to assess integrity (comparable to how NatureServe maintains a database of conservation status rank factors)
e) ability to maintain 3 levels of EORANKSPECS (level 1, 2, 3) and,
f) a revised EORANK file that allows ecologists to specify the level of rank being applied (Level 1, 2, or 3) and the metrics used to rank an occurrence.

We are encouraging subnational ecologists to adopt a single, set of consistent factors, all scaled to a the same range for ranking occurrences, rather than adjusting their rank standard based on subnational priorities. Relying on a consistently scaled set of factors is consistent with how element ranks are developed. Addressing conservation priorities for occurernces in a state should be addressed in a separate step.

It will be helpful to have an overall consistency to the metrics used to assess ecological integrity across the range-wide distribution of ecosystem types, so that consistent and repeatable assessments of ecological integrity are available. **That said, metrics are constantly being developed and revised, and fundamentally, what is critical is that they be placed in the framework of the overall conceptual model of ecological integrity, so that regardless of the metrics used, a comparable index of ecological integrity is provided by member of the Network.**   Programs and partners are encouraged to test and refine these methods.

Figure 10. A model for how to incoporate ecological integrity assessment methods in NatureServe's Biotics database. Metrics for ecological integrity are stored in a "metrics database," an ecological integrity assessment protocol, at 3 possible levels, with the specified metrics, is stored elsewhere (EO RANK SPECS), and an expanded element occurrence record is provided that allows ranks be to be assigned at any or all levels .



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