An Introduction to NatureServe's Ecological Integrity Assessment Method

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Abstract

Ecological integrity concepts provide valuable information for assessing ecosystem condition and management effectiveness, and are an important component of ecologically based monitoring. The goal of an ecological integrity assessment (EIA) is to provide a succinct assessment of the current status of the composition, structure, processes, and connectivity of a particular occurrence of an ecosystem type. Ecological integrity is interpreted in light of reference conditions based on natural ranges of variation, and with a practical interpretation of site information that can inform management decisions and guide conservation and restoration activities. We first introduce the basic concepts of ecological integrity and then outline a series of steps that we used to develop and implement an EIA. These steps include: 1) the role of ecosystem classification and the geographic extent and time scale of the assessment, 2) development of conceptual models using information on natural ranges of variability and current studies, 3) identification of indicators at multiple levels of assessment (remote, rapid, intensive), 4) selection of metrics that most effectively assess the main ecological factors of an ecosystem type and that respond to stressors that drive degradation, 5) identification of assessment points and thresholds for each metric, and 6) development of briefs, scorecards, and reports that summarize the ecological integrity information. We conclude by noting the role that ecological integrity assessments have in other assessments, including that of ecosystem services, climate change assessments, at-risk ecosystem assessments, and watershed and landscape assessments.

Contents

Introduction to Ecological Integrity

Terrestrial ecosystems are complex combinations of plants, animals, soils, and other abiotic factors that provide critical ecological benefits, such as water quality improvement, flood control, carbon storage, climate regulation, aesthetic enjoyment, and biodiversity support. But their complexity also makes it challenging to characterize their ecological condition. Assessing that condition has become important, as broad scale stressors such as land use, invasive species, and climate change alter the processes and benefits that ecosystems provide. For that reason, ecologists have pursued a variety of methods to track and respond to declines in ecosystem condition, including ecological integrity methods.

Building on the related concepts of biological integrity and ecological health, ecological integrity is a core concept for assessing and reporting on ecological condition (Harwell et al. 1999, Andreasen 2001). Ecological integrity can be defined as "*an assessment of the structure, composition, function, and connectivity of an ecosystem as compared to reference ecosystems operating within the bounds of natural or historical disturbance regimes*" (Parrish et al. 2003, Faber-Langendoen et al. 2016c). To have integrity, an ecosystem should be relatively unimpaired across a range of ecological attributes and spatial and temporal scales. The concept of integrity depends on an understanding of how the presence and impact of human activity relates to natural ecological patterns and processes. This information provides land managers, conservationists, scientists, and agencies with critical information on factors that may be degrading, maintaining, or helping to restore an ecosystem.

Here we present an overview of our ecological integrity methods, in step-wise fashion, from the role of ecosystem classification and the geographic extent and time scale of the assessment, through the development of conceptual models, identification of indicators, assessment points and thresholds, and ending with the reporting of ecological integrity information through briefs, scorecards, and reports. We conclude by highlighting the role of ecological integrity assessment information in multiple kinds of ecological assessments.

The NatureServe Ecological Integrity Assessment Method

Background

NatureServe and its network partners from state Natural Heritage Programs, in collaboration with a variety of agency partners, have developed methods to assess ecosystem condition, structured around the concept of ecological integrity (NatureServe 2002, Faber-Langendoen et al. 2012, 2016c). Critical to the methodology are coherent and consistent conceptual ecological models for specific ecosystem types that identify the major ecological factors and key attributes for which indicators are most needed. Identifying the ecological factors we most need to assess and monitor is key to making management decisions that will maintain ecological integrity (Noon 2003). The process of modeling and indicator selection leads to a practical set of metrics, by which field measures can be collected and rated. In addition, we develop the EIA method for various data sources (Level 1 remote-sensing data, Level 2 rapid field data, and Level 3 intensive field data), practical at the state level, but repeatable across ecosystems, states, and wherever applied nationally (Faber-Langendoen et al. 2012).

Our approach is similar to other multi-metric approaches, such as the Index of Biotic Integrity and the Tiered Aquatic Life Use frameworks for aquatic systems (Karr and Chu 1999, Davies and Jackson 2006), a variety of state-based wetland rapid assessment methods (see Fennessy et al. 2007a, Wardrop et al. 2013), EPAs Vegetation Multi-Metric Index (USEPA 2016), and Rangeland Health indicators ((Pellant et al. 2005). Common to each of these methods is that metrics are rated by comparing measured values with values expected under relatively unimpaired conditions (reference standard). Rating multiple metrics, across multiple ecological factors provides a picture of the overall integrity of the ecosystem; in essence, these metrics provide a standard "biophysical exam" that assesses how well an ecosystem is doing.

The EIA method can be applied in multiple ways, reflecting the importance of assessing ecological condition (Box A). NatureServe has developed a series of general EIA templates that are broadly applicable (Faber-Langendoen et al. 2012). These general templates can be fine-tuned for ecological systems specific to a particular geographic area. EIAs have been developed for upland, wetland, and riparian ecological systems throughout the United States (Faber-Langendoen 2008; Unnasch et al. 2009; Faber-Langendoen et al. 2012, Comer et al. 2013, Nordman et al. 2016) and within specific states (e.g., Lemly and Rocchio 2009, Rocchio and Crawford 2011, Nichols and Faber-Langendoen 2012, Lemly and Gilligan 2015,T. Foti pers. comm. 2016).

Box A: Ecological Integrity Applications

- Determine range in integrity of an ecosystem within a landscape or watershed (Lemly et al. 2013).
- Identify occurrences with the highest levels of integrity within a jurisdiction (Rocchio et al. 2015).
- Prioritize occurrences for conservation and management actions (Rocchio et al. 2015).
- Track status of occurrences over time, using cost-effective, reliable measures of integrity (Tierney et al. 2009).
- Address ecosystems at-risk by providing information on the integrity of all remaining occurrences (Marriott et al. 2016).
- Prioritize field survey work.
- Assess restoration and mitigation efforts based on reference standard sites (Brooks et al. 2016).
- Inform population viability for species closely linked to specific ecosystems,

The Basic Steps in Developing an EIA

Ecological Integrity Assessments are developed using the following steps:

1) Identify the thematic, spatial, and temporal scales of interest; specifically, the ecosystem types that are to be assessed, and the geographic and time scales of evaluation. Use ecological classifications at multiple classification scales to guide the selection of ecosystem types.
2) Develop a general conceptual model that draws from information on historic and natural ranges of variation, as well as current studies, to identify the major ecological factors and key ecological attributes of the ecosystem. Summarize the model using a narrative description, including how the attributes are impacted by various natural drivers and stressors.
3) Use a three level assessment approach: (i) remote sensing, (ii) rapid ground, and (iii) intensive ground-based assessments. The 3-level approach provides both increasing accuracy of ecological integrity ratings when all three levels are used, and increased flexibility in choosing a level of assessment suitable for the application.
4) Identify the indicators and related metrics that best represent the ecological attributes. This can be an iterative process, based on a variety of criteria, including scientific, management, and operational considerations.
5) Identify assessment points and thresholds that guide the ratings for each metric, including through field assessments and validation.
6) Provide briefs, scorecards, and reports that facilitate interpretation of the integrity of various attributes, and the integrity of the overall system.

A general note of caution: ecosystems are far too complex to be fully represented by a suite of key ecological attributes, indicators, and metrics. As such, our efforts to assess ecological integrity are approximations of our current understanding of any ecosystem, and the models, indicators and reporting formats will be periodically reevaluated as our understanding of ecosystems evolves.

Below, we present each of these steps in more detail.

Step 1. Establish Scales of Interest: Types, Time, and Geography

Thematic Scale: Identifying Ecosystem Types

Ecological classifications help managers better understand natural variability within and among types, and thus play an important role in helping to distinguish sites that differ across a gradients of conditions and stressors (Collins et al. 2006). For example, the hydrologic characteristics of tidal salt marshes are distinct from that of depressional marshes and floodplain forests (Collins et al. 2006). Classifications also provide a means to establishing "ecological equivalency;" e.g., that a prairie restoration in the Black Hills montane region is based on the Black Hills Montane Grassland association, rather than a Great Plains grassland type found at lower elevations.

Ecosystems can be defined broadly or narrowly, depending on the needs of the project. The level of classification specificity is sometimes referred to as the "thematic" scale. For example, in North America, we can identify the Central North American Grassland division at a broad thematic scale and we can identify the Flint Hills Tallgrass Prairie association or Black Hills Montane Grassland at a fine thematic scale. Depending on the purpose of the project, various phases or subtypes are described within a type to reflect structural and ecological dynamics. For example, some Great Plains grassland may have shrubby phases that are set back by periodic fires. In the absence of fires, these shrubs may dominate and displace the grasses, and eventually form a different ecosystem type or alternative state.

In choosing a classification for use in ecological integrity assessments, we prefer ones that a) are multi-scaled (so different projects can identify the thematic scale appropriate to the study), b) use both biotic and abiotic factors in defining types (so that the overall natural variability of ecosystems is accounted for), and c) are well-established, and used by multiple organizations (to increase the likelihood of accessing available data from other studies). A number of such classifications are available for describing ecosystems (see Box B).

Spatial and Temporal Scale

Applications of EIA vary from spatial scales of individual sites to sites across watersheds, landscapes and regions, and temporal scales from a one time, snapshot assessment to monitoring over many time periods. Spatial scales can vary along two common endpoints. The small spatial scale endpoint includes choosing and assessing one or several target sites, sometimes comparing them to other sites (e.g., a restoration site compared to reference sites). At the large spatial scale endpoint, all locations of a particular ecosystem type across a jurisdiction or region are chosen and assessed. The temporal scale is also important, and includes consideration of the timing of data collection (e.g., summer only or year-round) and the planned duration (e.g., one time or repeated).

In either case, the manner in which sites are chosen varies from preferential sampling to statistical sampling. For example, preferential sampling is used when the goal is to document the remaining exemplary occurrences of ecosystems in a watershed, state or region, or to sample the full range of variation in a particular type of ecosystem (Rolecek et al. 2007, Michalcová et al. 2011). Statistical sampling is used where sites need to be located objectively, so that inferences about status and trends can be made. Such designs could be applied to a local area (e.g., pitch pine woodlands in Acadia National Park greater than 0.5 ha in areal extent, or all wetlands within a watershed), or across an entire state or nation (e.g. the National Wetland Condition Assessment program by U.S. Environmental Protection Agency (2016), and the forest Assessment for New York State by the U.S. Forest Service (Widmann et al. 2015)).

Identifying spatial and temporal scales are essential for data collection, and helps guide the development of the conceptual diagram and indicators (Mitchell et al. 2014). Some indicators are only feasible if temporal considerations are brought in (e.g., growth rates of trees); others are only interpretable at certain spatial scales (e.g., fragmentation).

Step 2. Conceptual Ecological Models

2.1 The Goals of Conceptual Models

The development of conceptual ecological models to identify key system components, linkages, and processes is a critical step in the design of assessment and monitoring programs (Fig. 1). The models are developed to clarify our knowledge of ecosystem structure and dynamics (Noon 2003, Bestelmeyer et al. 2010). They help identify the key attributes, indicators, and metrics that provide managers with the information they need to understand the response of the ecosystem to the drivers and stressors affecting the ecosystem, and when to initiate management activities (Fig 1). The models typically take the form of summary narratives, often combined with simple or complex figures that summarize the relationships among ecological attributes and their responses to stressors.

We can summarize the key goals of conceptual ecological modeling as follows (see Mitchell et al. 2006):

Goal A. *Define the Phases and States of the Ecosystem:* Identify the various phases of the ecosystem, including major structural phases, and their relation to other natural and ruderal types.

Example: Describe relation of mangroves to salt marshes in warm-temperate regions.
Example: Describe the state and transitions of salt marsh ecosystem to lack of sedimentation and to sea-level rise.

Goal B. *Identify Drivers and Stressors:* Identify the most important external ecological drivers and anthropogenic stressors acting upon the ecosystem, to support and inform management decisions.

Example: Identify tidal patterns and their response to sea-level rise.
Example: Describe the response of salt marshes to canals and other land uses.

Goal C. *Identify Key Species, Ecological Processes, and Transitions:* Identify the selected taxa, internal ecological processes, and transitions between states that support and inform management decisions affecting the ecosystem.

Example: Document status and trends of focal resident bird species in a salt marsh.
Example: Describe surface elevation dynamics in salt marshes, in relation to accretion, subsidence and sea-level rise, and transitions to other states
Example: Identify core abiotic and biotic water quality indicators reflective of eutrophication.

2.2. The Basics of Conceptual Ecological Models

Despite the large diversity of ecosystems, they often share broadly common components. For most terrestrial upland or wetland models, typical primary ecological factors include landscape context (landscape, buffer), on-site condition (vegetation, hydrology, soil), and size (NatureServe 2002, Parkes et al. 2003, Oliver et al. 2007) (Fig. 2). Greater specificity can be developed by bringing in key ecological attributes, such as animals (e.g., birds, fish), soil and water chemistry, or particular ecological processes (e.g., fire flooding, and productivity). The models include both the "inner workings", flooding, and productivity). The models include both the "inner workings" (condition) and the "outer workings" (landscape context) of an ecosystem (Leroux et al. 2007), and both are influenced by the size of the local ecosystem patch.

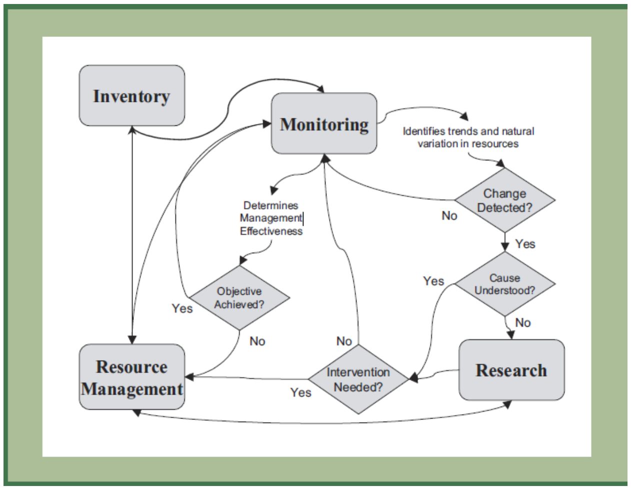


Figure 1. Relationships between monitoring, inventories, research, and natural resource management activities (Mitchell et al. 2006).

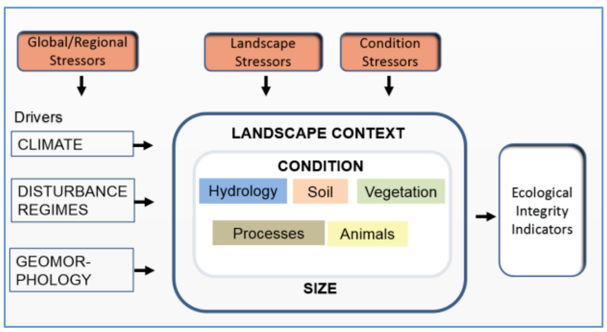


Figure 2. Conceptual ecological model for assessing ecological integrity. The major ecological factors of ecological integrity are shown for wetlands and uplands. The model can be expanded to include additional measures of ecological Integrity, such as animals (birds, mammals, amphibians, macroinvertebrates, etc.) and ecological processes or functions (water quality, productivity, etc.).

We use the following terminology in developing conceptual models:

- **Ecosystem drivers** are major external driving forces such as climate, hydrology, and natural disturbance regimes (e.g., hurricanes, droughts, fire) that have large-scale influences on natural ecosystems.
- **Stressors** are physical, chemical, or biological perturbations to a system that are either foreign to that system, or natural to the system but applied at an excessive or deficient level. Stressors cause significant changes in the ecological components, patterns, and processes within natural systems. Examples include water withdrawal, sea level rise, invasive exotic species, land-use change, and water pollution.
- **States** are the characteristic combination of biotic and abiotic components that define types or phases of ecosystems (e.g., early, mid, and late seral/old growth stages in forest types). States both control and reflect ecological processes.
- **Major Ecological Factors** (MEF) broadly describe characteristics of the ecosystem. For basic models of general ecosystem types, identification of MEFs may be sufficient for describing the ecosystem and identifying the indicators.
- **Key Ecological Attributes** (KEA) of an ecosystem are subsets of major ecological factors that are critical to a particular aspect of the ecosystem's response to both natural ecological processes and disturbances and human-caused disturbances (Parrish et al. 2003). Alterations to key ecological attributes can lead to the degradation or loss of that ecosystem. KEAs are helpful for detailed models of specific ecosystem types.
- **Indicators** are a select subset of measurable ecosystem features or processes that are particularly information-rich in that their values are indicative of the integrity of the larger ecological system to which they belong (Noon 2002). Indicators are typically chosen across all MEFs and KEAs.

    - **Focal taxa** are a special kind of indicator that, by virtue of their sensitivity or exposure to stress, their association with other taxa, or their life history characteristics, might serve as useful indicator species of ecological integrity. Focal taxa include foundation species, keystone species, and ecosystem engineers (Ellison et al. 2005).

Box B. The EcoVeg Approach, Ecological Systems, and other Ecological Classifications

The EcoVeg approach (Faber-Langendoen et al. 2014) integrates vegetation and ecology into a multi-tiered hierarchy of ecosystem types, both upland and wetland. The approach is used by a number of related classifications, including the International Vegetation Classification (IVC), which covers vegetated ecosystems around the world, the U.S. National Vegetation Classification (USNVC), (FGDC 2008), and the Canadian National Vegetation Classification (CNVC) (Baldwin and Meades 2008).

A related classification approach, the Ecological Systems classification (Comer et al. 2003), can be used in conjunction with the EcoVeg-based classifications. Ecological systems provide a spatial-ecologic perspective on the relation of associations and alliances (fine-scale NVC types), integrating vegetation with natural dynamics, soils, hydrology, landscape setting, and other ecological processes. They can also provide a mapping application of the NVCs, much as soil associations help portray the spatial-ecologic relations among soil series in a soil taxonomic hierarchy (Comer and Schulz 2007).

Together these classifications meet several important needs for ecological integrity assessments, including:

- a multi-level, ecologically based structure that allow users to address conservation and management concerns at the level relevant to their work.
- a comprehensive list of ecosystem types across the landscape or watershed, both upland and wetland.
- an integrated biotic and abiotic approach that is effective at constraining both biotic and abiotic variability within a type.
- information on the relative rarity or at-risk status of ecosystem types (endangered ecosystem).
- support federal standards (e.g., the USNVC is a federal standard for U.S. federal agencies, facilitating sharing of information on ecosystem types (FGDC 2008).
- access to readily available web-based information (e.g., usnvc.org, cnvc-cnvc.ca, and natureserve.org).
- inform comprehensive maps of ecosystems (in the U.S., see www.landfire.gov, www.landscope.org, gapanalysis.usgs.gov; for U.S. National Parks, see Vegetation Mapping Inventory).

In North America, many state or provincial programs have either adopted these classifications directly (e.g., Hoagland 2000), or developed closely compatible classifications (e.g., Gawler and Cutko 2010).

For wetlands, there are a number of specialized classifications available that can be used in conjunction with the USNVC or CNVC, including (see citations in Faber-Langendoen et al. 2012, 2016a):

- National Wetlands Inventory (NWI)
- Hydrogeomorphic (HGM) classification
- Canadian Wetland Classification System

For a comprehensive classification of coastal and marine ecosystems, see the Coastal Marine Ecological Classification Standard (CMECS) (FGDC 2012).

- **Metrics** are the specific form of an indicator, specifying both a) the *measures* needed to evaluate the indicator, and b) the *assessment points and ratings* by which those measures are informative of the integrity of the ecosystem. For example, *measures* of percent cover and coefficients of conservatism are needed for each species when applying the floristic quality index metric; the metric defines the particular equation (e.g., weighted mean C) and the *assessment points* that determine the rating assigned to the values (e.g., a particular range of weighted mean C values = A-rating) (Swink and Wilhelm 1979, Bourdaghs 2012).

- **Focal Resources** are resources that, by virtue of their special protection, public appeal, or other management significance, are important for monitoring regardless of current threats or whether they are indicative of ecosystem integrity.

2.3. Conceptual Ecological Models and the Natural or Historic Range of Variability

Species and native ecosystems have evolved within dynamic environments over long periods of time. The structure and species composition of any ecosystem naturally varies over time and across regions, and experiences varying disturbances from fire, drought, wind damage, or flooding. Natural resource managers often use the concept of a natural range of variability (NRV) (essentially synonymous with historical range of variability HRV) to describe these long term historical characteristics of ecosystems (e.g., Landres et al. 1999, Romme et al. 2012). Our knowledge of NRV is based on historical information, paleoecological studies of past conditions, research on current condition of relatively free of human stressors, and models of ecosystem dynamics (Parrish et al. 2003, Stoddard et al. 2006, Brewer and Menzel 2009). This knowledge provides important clues about the long-term ecological processes and natural disturbances that shape ecosystems, the flux and succession of species, and even the relative role of humans in shaping the systems. This knowledge provides a reference for gauging the effects of current anthropogenic stressors (Landres et al. 1999). For these reasons, understanding NRV is an important part of conceptual ecological modeling (See Box C).

There is concern that current ecological conditions are changing so rapidly that natural and historical information is no longer relevant. But, there are a number of ways in which NRV remains an important guide for our conceptual models of ecological integrity (Higgs 2003, Higgs and Hobbs 2010):

- First, it is the knowledge of natural variability that informs our goals and evaluations of current conditions, but this knowledge does not *a priori* constrain how we state desired conditions for good ecological integrity.
- Second, to suggest that we can simply take over the management of natural ecosystems without understanding NRV is to invite failures in these complex systems.
- Third, the purpose of understanding NRV is not to lock us in the past, but to ensure that we connect the historical ecological patterns and processes to the present and future.

Box C. Natural Range of Variability (NRV) and Indicators – Species Richness in Great Plains Grasslands

Symstad and Jonas (2014) compiled information on species richness and evenness indicators for a variety of Great Plains grasslands. Characterizing NRV for these indicators was challenging because there was no readily accessible historical record and Great Plains grasslands have a history of altered natural conditions, included altered grazing and fire patterns. The authors used sites that had both long term data (from 1930s to present) and experimental treatments of stressors and natural drivers, such as nitrogen addition, grazing, and fire to describe the NRV. The available long term data showed that the temporal variability in species richness was fairly consistent within various prairie types, but there was sufficient variability to mask undesirable changes from nitrogen additions or altered fire regimes, especially when coupled with periodically severe droughts. Thus the authors suggested using a narrow NRV for reference conditions of species richness. For example, for reference conditions for mid slopes of ungrazed Flint Hills tallgrass prairie in Kansas, an A rating could be set at 35-45 spp./ 50 m^2, with an A/B assessment point when values are < 35 spp./m^2. A C/D assessment point could be set at levels totally outside the NRV, in this case <20 spp. / 50 m^2 (see their Fig. 8.8). Given some of the challenges of interpreting this metric, it is recommended that it be one component of a suite of vegetation metrics, including primary production (biomass or cover), woody structure, increaser/decreaser indicator species and exotics.

- Fourth, understanding NRV will ensure that we can anticipate change and emphasize resilience in the face of future changes.

Thus, when discussing NRV, our goal is not to simplistically distinguish "natural" as referring only to "pristine conditions." That is not tenable, given the long interactions between humans and the environment. But neither do we want to collapse human activity (culture) into an extension of natural processes, as if humans are just another creature. Rather we can look at 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). For example, our current concepts of ecological integrity with respect to fire and succession in temperate forests differ from those in the early twentieth century, when the role of fire was often seen in negative terms. In these ways, NRV takes us beyond a simple interpretation of what is natural to engaging us to think through how our actions and goals can sustain natural ecosystems.

2.4. Conceptual Ecological Models and Reference Sites

Our models and our understanding of the NRV need not be interpreted solely from the historical record; rather, we can bring in information from reference sites currently present on the landscape. As described by Brooks et al. (2016), reference sites represent areas that are intact or with minimal human disturbance; i.e., "reference standard" or "exemplary ecosystem occurrences." In effect, they provide us with an understanding of the current range of conditions. Given the extensive loss of ecosystems in many jurisdictions, current ecological conditions may only represent a portion of the NRV, and it may also include current conditions that are outside the NRV. Thus an important part of the modeling process is to determine which conditions most closely resemble the NRV. Where such conditions exist, these sites can serve as the minimally disturbed reference condition (MDC). Where current conditions no longer reflect the NRV, the MDC can sometimes be inferred from other studies. Failing that, a least disturbed condition (LDC) or best attainable condition (BAC) may be used[1] (Sutula et al. 2006).

Typically, the initial approach to identifying reference sites is to rely on a combination of factors, including naturalness, ecological integrity, and lack of evidence of human disturbances. Naturalness and integrity are often judged by historical fidelity (connectivity in time), a full complement of native species, characteristic species dominance and productivity, presence of typical ecological processes such as fire, flooding, and windstorms, and minimal evidence of anthropogenic stressors (Woodley 2010). This information can be used to set levels of ecological integrity along a gradient from minimally disturbed conditions to severely impacted sites (Davies and Jackson 2006). We use this approach as a guide for our conceptual modeling, using a general narrative that identifies the typical characteristics of a reference standard based on NRV, and a gradient of conditions that reflect increasing anthropogenic impacts that degrade the system (Table 1).

[1] When choosing a reference standard, one needs to choose whether such a standard represents the Minimally Disturbed Condition (MDC) or Least Disturbed Condition (LDC), or a combination of the two, based on best attainable condition (BAC). Huggins and Dzialowski (2005) note that MDC and LDC set the high and low end of what could be considered reference standard condition. They go on to say that "these two definitions can be used to help define the Best Achievable Conditions (BAC's), which are conditions that are equivalent to LDC's where the best possible management practices are in use. The MDC's and LDC's set the upper and lower limits of the BAC's. Using the population distribution of measures of biological condition associated with a reference population might provide some insights regarding the potential relationship between the MDC and LDC for a particular region."

Step 3. Three-Level Approach to Identifying Indicators

Ecological integrity can be assessed at different levels, (Brooks et al. 2004, U.S. EPA 2006, Wardrop et al. 2013) depending on the purpose and design of the project. Level 1 (Remote Assessment) relies primarily on remote sensing-based indicators. Level 2 (Rapid Field Assessment) uses relatively simple semi-quantitative or quantitative wetland condition indicators that are readily observed in the field, often supplemented by a stressor checklist (see below). Level 3 (Intensive Field Assessment) requires detailed quantitative field measurements, and may include intensive versions of some of the rapid metrics (Stein et al. 2009).

The "3-level approach" to assessments 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 (Table 2). Because the purpose is the same for all three levels of assessment - to measure the status of ecological integrity of a site, or across a region - it is important that the identification of ecological attributes and the selection of metrics be coordinated. That is, if invasive or woody species encroachment are identified as key stressors, metrics that address these key issues should be identified for each level (Solek et al. 2011).

Some projects may focus on one level (e.g., many wetland rapid assessments); other have multiple levels that are designed to work together, depending on the project. For example, the U.S. Forest Service Forest Inventory and Analysis program conducts regular surveys of forests across the U.S. by remote sensing of the presence of forests and their patch size (P1 = Level 1 in Table 2), rapid plots that characterize tree species (P2), and intensive plots that characterize shrub, herb and nonvascular species (P3). Sampling can also be stratified by these levels, whereby a comprehensive set of sites are rated using Level 1 indicators, a subset are sampled using Level 2 indicators, and finally, a select set are sampled with Level 3 indicators. The process should lead to an increasing accuracy of assessment (Solek et al. 2011).

Level 1 assessments are becoming increasingly powerful, as remote-sensing indicators are calibrated against ground data, and as we gain a better understanding of the key stressors that affect the ecological integrity of systems. The methods typically integrate multiple layers of information into an overall synthetic index. NatureServe and Network Landscape Integrity Model builds on the growing body of published methods for spatially based ecological effects assessment across landscapes (Comer and Faber-Langendoen 2013, Rocchio et al. 2015) (Fig. 3). The overall index can also be decomposed into individual stressors or sets of stressors, to determine which may be most important.

Level 2 (rapid, field-based) assessments evaluate ecological condition using a readily observable field indicators. They are structured tools combining scientific understanding of ecosystem structure, composition, processes, and connectivity with best professional judgment in a consistent, systematic, and repeatable manner (Sutula et al. 2006). Level 2 assessments rely primarily on relatively rapid (~2 - 4 hour) field-based site visits, but this may vary, depending on the purposes of the assessment and the size and complexity of the assessment area. They have proven to be very effective in wetland assessments as mitigation and restoration tools, and they are in use by many state wetland programs (Fennessy et al. 2007a). They can be more or less rapid, depending on whether additional supporting data are desirable (e.g., a basic vegetation plot data allows user to supplement a Level 2 assessment with FQA scores.

Table 1. General ecological integrity definitions of reference conditions (adapted from Faber-Langendoen et al. 2012, Table A11). Size is not required for ecological integrity ratings.

Rank	Description
A (intact, excellent)	Occurrence or observation meets reference conditions with respect to major ecological factors functioning within the bounds of natural disturbance regimes. Characteristics include: • **landscape context** contains natural habitats that are essentially unfragmented (reflective of intact ecological processes) and with little to no stressors; • **condition,** including 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; • **size** is very large or much larger than the minimum dynamic area.
B (minimally disturbed, good)	Occurrence or observation is not among the highest quality examples**,** but nevertheless exhibits favorable characteristics with respect to major ecological factors functioning within the bounds of natural disturbance regimes. Characteristics include: • **landscape context** contains largely natural habitats that are minimally fragmented with few stressors; • **condition**, including 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 minor negative impact; and many key plant and animal indicators are present; • **size** is large or above the minimum dynamic area.
C (moderately disturbed, fair)	Occurrence or observation has a number of unfavorable characteristics with respect to major ecological factors and natural disturbance regimes. Characteristics include: • **landscape context** contains natural habitats that are moderately fragmented, with several stressors; • **condition**, including 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; • **size** is small or below, but near the minimum dynamic area. Some management is needed to maintain or restore[2] these major ecological factors.
D (severely disturbed, poor)	Occurrence or observation has severely altered characteristics (but still meets minimum criteria for the type) with respect to major ecological factors and natural disturbance regimes. Characteristics include: • **landscape context** contains little natural habitat, is very fragmented, with many stressors; • **condition**, including 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; • **size** is very small or well below the minimum dynamic area. There may be little long-term conservation value without substantial restoration, and such restoration may be difficult or uncertain.[3]

[8]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 historical trajectory" (SER 2004).(see SER 2004 for details).

[3]D-ranked sites present challenges. Whether a degraded type has "crossed the line" ("transformed" in the words of SER 2004) into a new ruderal or cultural type is a matter of classification criteria. Here we include D ranked examples as still identifiable to the type based on sufficient diagnostic criteria present.

Table 2. Summary of 3-level approach to conducting ecological integrity assessments (adapted from Brooks et al. 2004, U.S. EPA 2006).

Level 1 – Remote Assessment	**Level 2 – Rapid Assessment**	**Level 3 – Intensive Assessment**
General description: Remote or GIS-based assessment	*General description:* Rapid field-based assessment	*General description:* Intensive field-based assessment
Evaluates: Integrity of both on and off-site conditions around individual sites/occurrences using • Indicators on-site that are visible with remote sensing data • Indicators in the surrounding landscape / watershed	*Evaluates:* Integrity of individual sites using relatively simple field indicators • Very rapid assessment (visual observations with narrative) • Rapid assessment (standard indicators) • Hybrid assessment (rapid + some intensive indicators; e.g., vegetation data from plots)	*Evaluates:* Integrity of individual sites using quantitative, sometimes complex, field indicators • Metrics based on detailed knowledge of historic NRV and statistically analyzed data • Quantitative field sampling methods
Based on: • GIS and remote sensing data • Layers typically include: land cover, land use, ecosystem types • Stressor metrics (e.g., roads, other impervious surfaces, land use types)	*Based on:* • On-site condition metrics (e.g., vegetation, hydrology, and soils) • Landscape and buffer metrics • Stressor metrics (e.g., ditching, road crossings, and pollutant inputs)	*Based on:* • On-site condition metrics (e.g., vegetation, hydrology, and soils) • Landscape and buffer metrics • Stressor metrics (e.g., ditching, road crossings, and pollutant inputs)
Potential uses: • Identify priority sites • Identify status and trends of acreages across the landscape • Identify condition of ecosystem types across the landscape • Informs targeted restoration and monitoring	*Potential uses:* • Relatively inexpensive field observations across many sites • Informs monitoring for implementation of restoration, mitigation, or management projects • Landscape / watershed planning • General conservation and management planning	*Potential uses:* • Detailed field observations, with repeatable measurements, and statistical interpretations • Identify status and trends of ecosystems • Inform monitoring for restoration, mitigation, and management projects

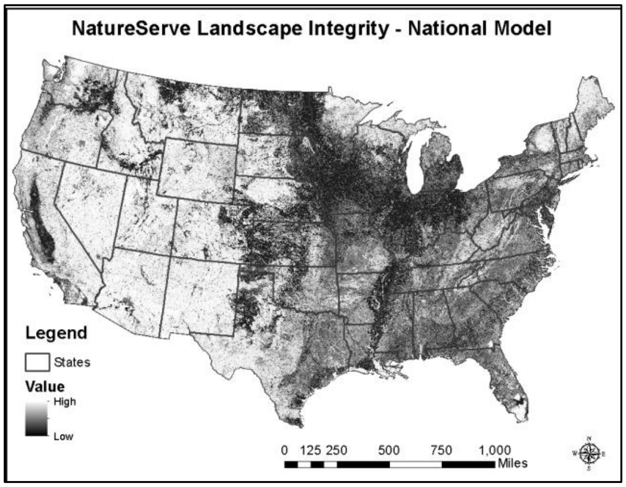


Figure 3. NatureServe national landscape integrity map, which is a 90-meter-pixel resolution continuous surface with values between 0.0 (high integrity or light shading) and 100 (low integrity or dark shading) (from Comer and Faber-Langendoen 2013).

Level 3 (intensive field based) assessments develop data that are rigorously collected, often with an explicit sampling design, to provide better opportunities to assess trends in ecological integrity over time. The quantitative aspect of the indicators lends themselves to more rigorous testing of the criteria for metric selection (see below). Because of their cost and complexity, Level 3 methods are often closely scrutinized to ensure that they address key decision-making goals. They are often highly structured methods, with detailed protocols that ensure a consistent, systematic, and repeatable method (Sutula et al. 2006).

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 Level 3. For example, data from Level 2 or Level 3 metrics can be used to calibrate the Level 1 remote-sensing based indicators (Mack 2006, Mita et al. 2007, Stein et al 2009).

Step 4. Selection of Indicators and Metrics

Having identified the ecosystem type (Step 1), worked through the conceptual ecological model to identify the MEFs and KEAs for which indicators and metrics are needed (Step 2), and made a choice regarding the level(s) of assessment (remote, rapid, intensive) (Step 3), the next step is to select metrics and indicators. As stated above, metrics are the specific form of an indicator, specifying both a) the *measures* needed to evaluate the indicators and b) the *thresholds and ratings* by which those measures are informative of the integrity or services of the ecosystem. For example *aboveground primary production* is an indicator of the Primary Production KEA for salt marshes. But it can be measured using a variety of methods, including a) by clipping once at the end of the season, b) sequentially during the growing season, or c) using proxy methods based on stem density or height (Day et al. 1989). Each of these methods uses different field measures and generates somewhat different numerical values; some may be hard to measure; others, expensive to measure. Thus, a specific metric of the indicator needs to be selected. For example, in salt marshes, the metric *Aboveground Standing Live Biomass* is a simple and effective proxy measure for biomass based on measuring stem height of the dominant grass, and can be used to quantify the Aboveground Primary Production indicator. Similarly, *Nonnative plant taxa* is a widely used indicator of ecological integrity, but various metrics are available to measure it, including *percent nonnative species richness*, *relative cover of nonnative taxa*, or the *absolute cover of nonnative taxa*. Ultimately, any assessment or monitoring of ecological integrity needs to specify the metric used for any indicator. We focus on selection of metrics throughout the rest of the document.

4.1. Selecting Metrics

The selection of metrics is focused on those that can detect changes in MEFs or KEAs, particularly changes caused by stressors (Box D, Box E). Metrics that measure a key ecological attribute and are sensitive to changes from stressors are referred to as "**Condition metrics;**" that is, metrics that directly measure changes to the KEAs or MEFs (e.g., hydroperiod, species richness, coarse woody debris). In contrast, "**stressor metrics**" directly measure stressors (e.g., number of ditches in a wetland, cut stumps in a forest), which are used to infer the condition or integrity of the system. We emphasize condition metrics because they are a more direct measure of ecological integrity. But we encourage independent assessment of stressors to guide the interpretation of ecological integrity or to inform management options. In cases where identifying a condition metric for a MEF or KEA is difficult or expensive, a well-validated stressor metric may be included.

Box D. Selecting a Good Metric – Snags and Coarse Woody Debris.

A **metric** should be informative about changes to one or more major ecological factors that reflect degradation of ecological integrity. For example, snags (dead standing trees) and fallen dead coarse woody debris (CWD) in Laurentian-Acadian mesic forests are good indicators of stand dynamics, because the old growth stage is the historically dominant state, and measures of these indicators increase as stands age. These dead wood components provide necessary habitat for many forest taxa. Logging and other land management practices may reduce the quantity and quality of dead wood, because they tend to create stands with smaller and younger live stems. As a result, less dead wood accumulates. There are a variety of metrics that could be used to assess these indicators. The Northeast Temperate Network (NETN) protocol used the relationships between live and dead wood to interpret snag abundance and CWD volume. A minimum snag density of at least 5 medium-large snags (≥ 30 cm diameter-at-breast-height) per hectare is inferred based on wildlife needs (see Tierney et al. 2009, and reference therein).

Metrics can be identified using a variety of expert-driven processes and through a series of data driven calibration tests. The scientific literature should first be searched to identify existing and tested metrics that are useful for measuring ecological integrity. For example, when developing the NatureServe wetland assessment method, we reviewed a variety of existing rapid assessment and monitoring materials, particularly the California Rapid Assessment Manual (Collins et al. 2006, Stein et al. 2011) and the Ohio Rapid Assessment Manual (Mack 2001), (Faber-Langendoen et al. 2008). Subsequently, we field tested and statistically validated the metrics (Faber-Langendoen et al. 2012, 2016b).

Candidate metrics can be filtered through a series of screening criteria (Andreasen et al. 2001, Tierney et al. 2009, Mitchell et al. 2014). When choosing metrics, we addressed the following

Box E. Screening Metrics: EPA's National Wetland Condition Assessment.

An example of metric screening comes from EPA's 2011 National Wetland Condition Assessment (REF). The agency found that the composition and abundance of plant species at a site reflected and influenced other ecological processes related to hydrology, water chemistry, and soil properties. These species integrates different wetland processes and plants respond to physical, chemical, and biological disturbances, making it a particularly valuable attribute to track. After careful screening of many candidate metrics, four were chosen for inclusion in the VMMI (USEPA 2016):

- A Floristic Quality Assessment Index (FQAI);
- Relative Importance of Native Plant Species;
- Number of Plant Species Tolerant to Disturbance; and
- Relative Cover of Native Monocot Species.

These metrics were then integrated into a national-scale **Vegetation Multimetric Index (VMMI),** as the best indicator of biological condition of wetlands.

four fundamental questions (Kurtz et al. 2001): 1) Is the metric ecologically relevant? Conceptually relevant metrics are related to the characteristics of the ecosystem or to the stressors that affect its integrity, and can provide information that is meaningful to resource managers. 2) Can the metric be feasibly implemented? The most feasible metrics can be sampled and measured using methods that are technically sound, appropriate, efficient, and inexpensive. 3) Is the response variability understood? Every metric has an associated measurement error, temporal variability, and spatial variability. The best metrics will have low error and variability compared to the NRV (Fig. 4). In other words, good metrics have high discriminatory ability, and the signal from the metric is not lost in measurement error or environmental noise. Ideally the metric is measured across a range of sites that span the gradient of stressor levels (DeKeyser et al. 2003) and verified to show a clear response to the stressor (See also Box C above). 4) Is the metric interpretable and useful? The best metrics provide information on ecological integrity that is meaningful to resource managers. For a practical summary of metric screening criteria, see Appendix A.

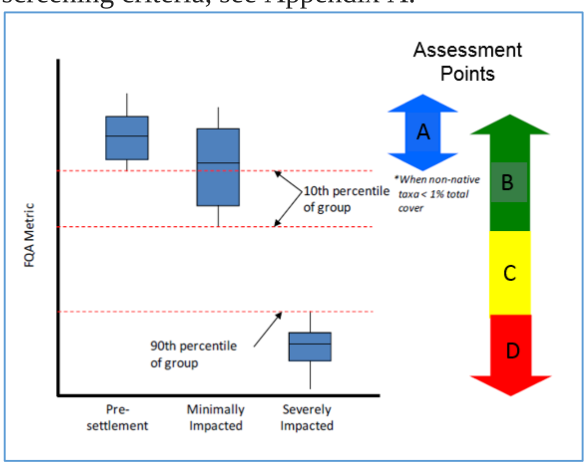


Figure 4. Diagram of Rapid FQA Assessment criteria, showing assessment point development (adapted from Bourdaghs 2012). Sites are assigned to data analysis groups (Presettlement, Minimally Impacted, and Severely Impacted). Assessment points, are set at designated percentiles of the FQA metric for each data analysis group. Three types of assessment points are provided: 1) Desired condition (A/B), 2) Early warning (B/C), and 3) Imminent collapse (C/D).

Step 5. Establish Assessment Points and Metric Ratings

5.1. The Basics

Using our knowledge of NRV as a guide to reference condition, we can determine both the natural variation in a metric and the variation caused by stressors. Thus, our next step in assessing ecological integrity is to establish ecological "assessment points" that distinguish expected or acceptable conditions from undesired ones that warrant further evaluation or management action (see Bennetts et al. 2007 regarding "assessment points" versus "thresholds" as guides for assessing ecosystem condition). These assessment points provide the information regarding the trajectory of a metric, whether it is moving away from the natural range of variation and towards an undesirable ecological threshold and possible ecosystem collapse, followed by a transition to an undesirable type.

To integrate the general reference condition framework introduced at the outset (Table 1), we now seek to establish assessment points based on the NRV and our knowledge from current reference sites. A simple reporting structure is used, such that **A (Excellent)** – the metric value lies well within its range of natural variability, **B (Good) -** The metric value lies within but is approaching the edge of it's the range of natural variability, **C (Fair) -** the metric value lies outside its range of natural variability, and represents a modest degree of ecological integrity degradation, and **D (Poor) -** the metric value lies well outside range of natural variability and represents significant ecological degradation, perhaps irreversible (see Fig. 4). Intermediate assessment points (e.g., A-, B-, C-) can be added where metric response is tightly linked to increasing stressor levels.

Examples of metrics and their ratings developed for Level 1, 2, and 3 assessments are provided in Tables 3, 4, and 5. In some cases it is not possible to distinguish Excellent from Good ratings, and a

3 category scale (Good, Fair, Poor) is used instead.

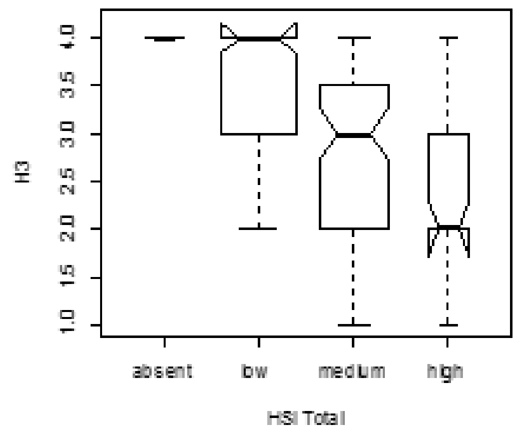
Selection of metric thresholds varies, depending on how finer-scaled types respond. For example, some metrics used for Floodplain Forests are the same across multiple wetland types, whereas others have ratings specific to Floodplain Forest (Table 4). Similarly, most forest metrics used for northeast temperate forests in Tierney et al. (2009) had identical ratings across all types, but the structural stage metric was distinct for red spruce-fir stands compared to oak or other hardwood stands, because lack of fire in spruce-fir types leads to a greater preponderance of old growth conditions as compared to fire-maintained oak types (Table 5).

5.2. Assessment Points, Stressor Checklists, and Validation

As can be seen from above, the ability to establish assessment points for condition metrics benefits from compiling information on stressors. As part of our ecological integrity assessment, we include a stressor checklist to systematically score the scope (percent area occupied) and severity of each stressor present at a site. The stressors are integrated into a stressor index that is used to rate the overall impact of stressors to various metrics and to overall ecological integrity. Various indices have been developed to assess these stressors, such as the Human Disturbance index of Rocchio (Lemly and Rocchio 2009), the Landscape Condition Model (Comer and Faber-Langendoen 2013, Hak and Comer 2016), and Human Stressor Index (Faber-Langendoen et al. 2015).

Use of stressor checklists also points to the need for ongoing field testing and validation of metrics. The initial selection of metrics and metric ratings should be based on field testing and later validated through rigorous testing. Stressor checklists are an important, and more-or-less independent, way to assign sites to a range of stressor levels. The response of the metrics to these stressor levels can validate the selection of the metrics (Figs. 4, 5). Further guidance on field testing and validation is found elsewhere (Mack 2006, Mita et al. 2007, Lemly and Rocchio 2009, Solek et al. 2011).

After the metrics used in an EIA method are well established, the stressor checklist is not required. However, it is still informative as supporting evidence for assessing ecological integrity, and is often valuable information for informing management activities.



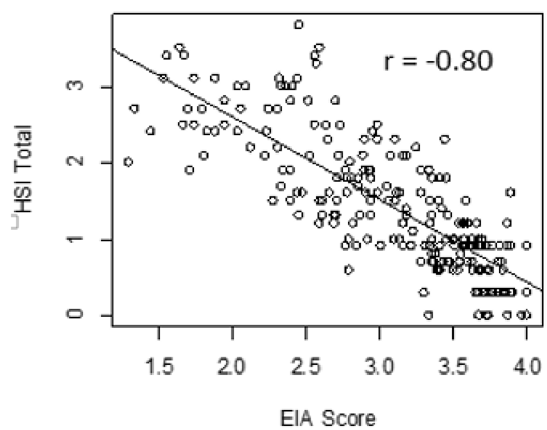


Figure 5. Field Testing and Validating the metrics used in NatureServe's wetland rapid assessment method. Data are from six states: Colorado, Indiana, Michigan, New Hampshire, New Jersey, and Washington (see Faber-Langendoen et al. 2016). a) Hydrologic Connectivity (H3) and its response to Human Stressor Index (HSI) Total (includes stressors found in both buffer and on-site). The Index is categorized into no Stressors (Absent) to High level of Stressors. B) Overall Ecological Integrity Assessment (EIA) score (rollup of all

metric scores shown in Table 6) and its response to HSI Total.

Step 6. Reporting the Results: The EIA Scorecard

After metrics are rated in the field and office, their ratings can be incorporated into a variety of forms. The goal is to ensure that the results reach the hands of decision-makers in a format that is accessible and useful (Miller et al. 2013, Mitchell et al. 2014). This could be a short factsheet that highlights the overall results of the EIA findings or a more detailed report that includes results of each of the individual metrics (Tables 6, 7). For monitoring programs, the reporting may be based on establishing baseline conditions, and detecting changes from that baseline.

One common approach for summarizing ecological integrity is a scorecard that displays the ratings for each metric (Table 6). This scorecard brings information together in a transparent way, allowing users to understand the status of various components of ecological integrity. Metrics ratings can be aggregated into major ecological factors (MEF) ratings, which in turn generate ratings for Landscape Context and (on-site) Condition, and ultimately, an Ecological Integrity rating. The scorecard approach is important, in that while any one metric may be failing, the scorecard provides a multi-factorial view of the system, and when multiple metrics are failing, may point graphically by summarizing the overall states and transitions, as commonly done for state-and-transition models (Fig. 6). Maps may also be shown, summarizing the EIA score across the range of a type (Fig. 7). Details of the NatureServe wetland scorecard protocol are provided in Faber-Langendoen et al. (2016a).

Table 3. Example of Level 1 (remote sensing based) Ecological Integrity Assessment metrics, developed for Great Basin Pinyon-Juniper Woodland metrics (from NatureServe 2011, see also Comer et al 2013). Ratings are shown in condensed form.

Key Ecological Attribute	Metric	Justification	Rating		
			Good (Sustainable)	Fair (Transitioning)	Poor (Degraded)
LANDSCAPE CONTEXT					
Landscape Connectivity	**Connectivity Predicted by Circuitscape**	Intact natural conditions support physical and biological dynamics occurring across diverse environmental conditions.	Connectivity is moderate to high; index is >0.6.	Connectivity is moderate to low; index is 0.6-0.2.	Connectivity is low; index is <0.2.
Landscape Condition	**Landscape Condition Model Index**	Land use impacts vary in their intensity, affecting ecological dynamics.	Cumulative level of impacts is sustainable. Index is > 0.8	Cumulative level of impacts is transitioning Index is 0.8 – 0.5	Cumulative level of impacts is degrading system. Index is< 0.5
CONDITION					
Fire Regime	**SCLASS Departure**	Departure from mixture of age classes predicted under NRV indicates uncharacteristic disturbance regime and declining integrity.	Mix of age classes is inside or near NRV. Departure is < 20%. SCLASS Departure Index is > 0.8.	Mix of age classes is near, but outside NRV. Departure is 20 -50%. SCLASS Departure Index is 0.8 – 0.5.	Mix of age classes is well outside NRV. Departure is > 50%. SCLASS Departure Index is < 0.5.
Native Species Composition	**Invasive Annual Cover**	Invasive annual vegetation displaces natural composition and provides fine fuels that significantly increase spread of catastrophic fire.	Mean cover of annuals is <5%. Invasive Annual Cover Index is >0.8.	Mean cover of annuals is 5-10%. Invasive Annual Cover Index is 0.8-0.5.	Mean cover of annuals is >15%. Invasive Annual Cover Index is <0.5
SIZE					
Relative Extent	**Change in Extent**	Proportion of change from conversion to other land cover.	80-100% remains.	50-80% remains.	<50% remains.

Table 4. Example of a Level 2 (rapid field based) Ecological Integrity Assessment, developed for *Temperate Flooded & Swamp Forest* (Faber-Langendoen et al. 2012, 2016). Not shown are B through D ratings. Shaded vegetation metrics could be replaced by a rapid Floristic Quality Assessment, preferably calibrated to be specific for Floodplain Forests (see Bourdaghs 2012).

MAJOR ECOLOGICAL FACTOR	METRIC NAME	RATING A (EXCELLENT)
LANDSCAPE CONTEXT		
LANDSCAPE	Contiguous Natural Land Cover	Intact: Embedded in 90–100% natural habitat around AA.
	Land Use Index	Average Land Use Score = 9.5–10
BUFFER	Perimeter with Natural Buffer	Natural buffer is 100% of perimeter
	Width of Natural Buffer	Average buffer width is >100 m, adjusted for slope
	Condition of Natural Buffer	Buffer is characterized by abundant (>95%) cover of native vegetation, with intact soils…..
CONDITION		
VEGETATION	Native Plant Species Cover	>99% relative cover of native vascular plant species across strata.
	Invasive Nonnative Plant Species Cover	Invasive nonnative plant species apparently absent.
	Native Plant Species Composition	Native plant composition (species abundance ,diversity) with expected natural conditions: • Typical range of native diagnostic species present; AND, • Native species sensitive to anthropogenic degradation (native decreasers) all present, AND • Native species indicative of anthropogenic disturbance ….absent to minor
	Vegetation Structure	**FLOODED & SWAMP FOREST (NVC)**: Canopy a mosaic of small patches of different ages or sizes …. AND number of live stems of medium size (30–50 cm / 12-20"dbh) and large size (>50 cm / >20" dbh) well within expected range.
	Woody Regeneration [opt.]	**FLOODED & SWAMP FOREST (NVC)**: Native tree saplings and/or seedlings or shrubs common to the type present in expected amounts and diversity; obvious regeneration.
	Coarse Woody Debris [opt.]	**FLOODED & SWAMP FOREST (NVC)**: • Wide size-class diversity of standing snags and CWD (downed logs). • Larger size class (>30 cm dbh/12" dbh and >2 m/6' long) present with 5 or more snags per ha (2.5 ac), but not excessive numbers (suggesting disease or other problems). • CWD in various stages of decay.

HYDROLOGY	Water Source	**RIVERINE (HGM):** Water source is natural, site hydrology is dominated by precipitation, groundwater, or overbank flow. There is no indication of direct artificial water sources. Land use in the local drainage area of the wetland is primarily open space or low density, passive uses. Lacks point source discharges into or adjacent to the site.
	Hydroperiod	**RIVERINE (HGM):** Hydroperiod (flood frequency, duration, level, and timing) is characterized by natural patterns, with no major hydrologic stressors present. The channel/riparian zone is characterized by equilibrium conditions, with no evidence of severe aggradation or degradation indicative of altered hydroperiod (see field indicators table).
	Hydrologic Connectivity	**RIVERINE (HGM):** Completely connected to floodplain…. No geomorphic modifications made to contemporary floodplain. Channel is not unnaturally entrenched.
SOIL	Soil Condition	***ALL FRESHWATER NON-TIDAL WETLANDS:*** Little bare soil OR bare soil and soil disturbed areas are limited to naturally caused disturbances such as flood deposition or game trails, OR soil is naturally bare (e.g., playas). No disturbances are evident from trampling, erosion, soil compaction, ruts, sedimentation, or boat traffic.
SIZE		
SIZE	Comparative Size (Patch Type)	Very large size compared to other examples of the same type …or almost all of the area-sensitive indicator species within the range of the type are present.
	Change in Size [opt.]	Occurrence has not been artificially reduced (0%) from its original, natural extent; any detectable change in size is due to natural fluctuations.

Table 5: Example of Level 3 (intensive field based) Ecological Integrity Assessment. Metrics were developed for northeast U.S. temperate forest ecosystems in the National Park Service's Northeast Temperate Network. Med-lg trees are ≥ 30 cm diameter-at-breast-height. Tree regeneration stocking index varies by national park. Priority 1 pests are Asian longhorned beetle, emerald ash borer, and sudden oak death. Priority 2 pests are hemlock wooly adelgid, balsam wooly adelgid, beech bark disease and butternut canker. See Tierney et al. (2009) for more details.

Metric type	Metric	Rating: Good	Rating: Caution	Rating: Significant Concern
Landscape structure	Forest patch size	> 50 ha	10 - 50 ha	< 10 ha
Landscape structure	Anthropogenic landuse	< 10%	10 - 40%	> 40%
Vegetation Structure	Stand structural class	>= 70% of stands are late-successional	< 70% of stands are late-successional in northern hardwood, hemlock-hardwood, or upland-spruce-hardwood forest	
		>= 30% of stands are late-successional	< 30% of stands are late-successional in lowland spruce-hardwood forest	
		>= 25% of stands are late-successional	< 25% of stands are late-successional in oak forest	
	Snag abundance	>= 10% standing trees are snags and >=10% med-lg trees are snags	< 10% standing trees are snags or < 10% med-lg trees are snags	< 5 med-lg snags/ ha
	Coarse woody debris volume	> 15% live tree volume	5 - 15% live tree volume	< 5% live tree volume
Vegetation Composition	Tree regeneration	Seedling ratio >= 0	Seedling ratio < 0	Stocking index outside acceptable range
	Tree condition	Foliage problem < 10% <u>and</u> no priority 1 or 2 pests	Foliage problem 10-50% <u>or</u> priority 2 pest	Foliage problem > 50% <u>or</u> priority 1 pest
	Biotic homogenization	No change	Increasing homogenization	
	Indicator species - invasive exotic plants	No key invasive exotic plant species on most plots	1 to 3 key species per plot	4 or more key species per plot
	Indicator species - deer browse	No decrease in frequency of most browse-sensitive species	Decrease in frequency of most browsed species <u>or</u> increase in frequency of browse-avoided species	Decrease in frequency of most browsed species <u>and</u> increase in frequency of browse-avoided species
Vegetation Processes	Tree growth and mortality rates	Growth >= 60% mean and Mort <= 1.6%	Growth < 60% mean or Mort > 1.6%	
Soil	Soil chemistry - acid stress	Soil Ca:Al ratio > 4	Soil Ca:Al ratio 1 - 4	Soil Ca:Al ratio < 1
	Soil chemistry - nitrogen saturation	Soil C:N ratio > 25	Soil C:N ratio 20 - 25	Soil C:N ratio < 20

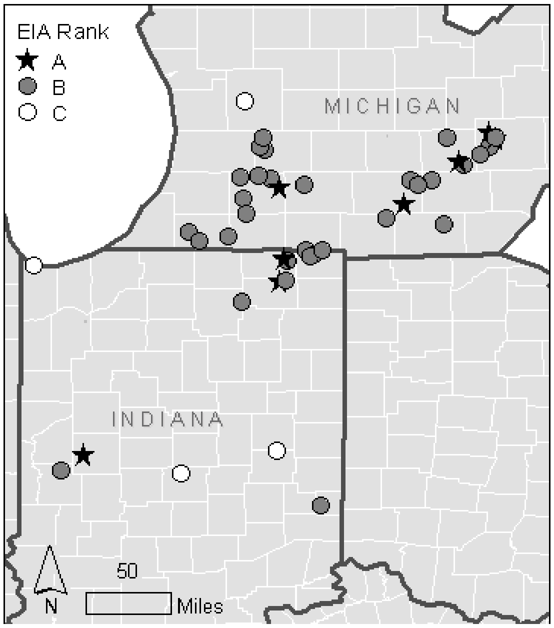


Figure 6. Distribution and overall EIA ratings of reference wetland sites for **Midwest Prairie Alkaline Fen (**NVC G183 on usnvc.org). Forty-four sites were visited, (A=9, B=31, C= 4), and metrics evaluated using the metrics shown in Fig. 2. These sites are tracked as element occurrences in the Natural Heritage databases in Indiana and Michigan (used with permission).

Table 6. Example of an ecological integrity scorecard, showing metric ratings for a floodplain forest site along the lower Arkansas River in Bent Co, Colorado. The individual metric ratings can be aggregated into an overall EIA rating.

Landscape Context	Rating
Landscape	
Contiguous Natural Cover Metric	A
Land Use Index Metric	C
Buffer	
Perimeter with Natural Buffer Metric	A
Width of Natural Buffer Metric	A
Condition of Natural Buffer Metric	C
Condition	
Vegetation	
Native Plant Species Cover Metric	C-
Invasive Nonnative Plant Species Cover Metric	D
Native Plant Species Composition Metric	D
Vegetation Structure Metric	C
Woody Regeneration Metric	D
Coarse Woody Debris Metric	A
Hydrology	
Water Source Metric	C
Hyroperiod Metric	D
Hydrologic Connectivity Metric	C
Soil	
Soil Condition Metric	A

Table 7. Ecological Integrity for forest ecosystems at three Northeast Temperate Network parks, based on a subset of ecological integrity metrics and data collected 2007-2010 (from Mitchell et al. 2014). See Table 5 above for metric ratings. Green indicates that the park (or a percentage of the park for multi-colored pie charts) is within the range of natural variation; yellow indicates that the surveillance (and first ecological) assessment point has been passed, and red indicates that the action (and second ecological) assessment point has been exceeded.

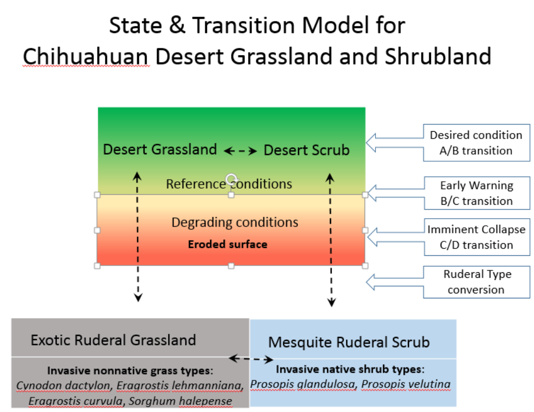


Figure 7. Summary presentation of model for a desert grassland type, summarizing the major transitions between states, both from natural disturbances (fire driven transitions from desert grassland to desert) and from reference state conditions to degraded states.

Taking Care of Business – Supporting Tools for EIA

Protocols for Metrics

Protocols are needed to ensure that consistent and clear guidance is provided on the measures needed for each metric. We have developed a standard format for documentation of each metric that includes the following pieces of information:

- definition of metric
- rationale for selection of the metric
- measurement protocol
- metric ratings
- rationale for scaling metric ratings
- citations

Protocols are now available for a number of NatureServe rapid assessment protocols (Level 2). The most developed and tested protocols include the NatureServe wetland rapid assessment metrics, both across states (Faber-Langendoen et al. 2012, 2016c) and for specific states (Colorado – Lemly and Gilligan 2015, New Hampshire – Nichols and Faber-Langendoen 2012, New Jersey – Walz et al. in prep, Washington – Rocchio and Crawford 2011). Recently, a native open pine rapid assessment protocol (longleaf pine, shortleaf pine, loblolly pine) was completed (Nordman et al. 2016). Other rapid assessment protocols cover all ecosystems in a state. Examples include Arkansas (Foti et al. 2016) and Washington (Rocchio and Crawford (2011). Finally, remote-sensing based protocols have been developed for entire ecoregions in the west, e.g. the Mojave Basin and Range (Comer et al. 2013). NatureServe maintains a comprehensive set of all metrics used for its EIA methods in the EcoObs database (see below).

Field Methods Guidance

Field methods for applying ecological integrity assessments vary, depending on the purpose of the assessment. Many of the details of the field method are guided by the protocols for the metrics (see above). Field manuals and field forms are available from NatureServe and a number of Natural Heritage Programs, including Colorado, Maine, New Hampshire, New Jersey, and Washington.

One critical step in conducting field work is defining the Assessment Area (AA). Two common choices are points and polygons. A **point based approach** (per Fennessy et al. 2007b, e.g., USEPA 2016) uses a fixed area around a point. The point is typically relatively small (0.5-2 ha). This approach offers a simplicity in terms of sampling design because:

- No mapped boundary of ecosystem type is required for an AA.
- Limits practical difficulties in the field of assessing a large AA.
- Repeat sampling/monitoring is relatively straightforward.

A **polygon or stand-level approach** (per Fennessy et al. 2007b, e.g. Faber-Langendoen et al. 2012) typically uses a mapped polygon that represents the local extent of a specific ecosystem type. The polygon could vary widely in size, from less than 1 hectare to many thousands of hectares. Using a polygon approach can be advantageous because:

- Mapping the boundaries of an ecosystem observation facilitates whole ecosystem and landscape interpretations.
- Decision makers and managers are often more interested in "stands" or "occurrences," rather than points.
- Size of the ecosystem observations can be integrated into the assessment.
- Comprehensive maps that display the range of conditions of an ecosystem across the entire landscape or watershed are possible.

Users will need to decide which approach best meets their objectives.

Reference Site Databases

As information accumulates on the status of ecosystems across a jurisdiction or geographic region, management of that data becomes critical. Given the large number of ecological condition assessments available, it is becoming increasingly important to manage that data. A number of tools currently exist, ranging from the single metric database of the Universal Floristic Quality Assessment Calculator (Freyman et al. 2016) to multi-metric databases for CRAM, Riparia, and many others (Brooks et al. 2016). Discussions have begun to make wetland reference sites available through a National Reference Wetlands Registry (RWR) (Brooks et al. 2016, Faber-Langendoen et al. 2016c). The RWR can become an important source of information for conservation, restoration, and mitigation of wetlands.

NatureServe uses a combination of databases “EcoObs” and “Biotics” to track high integrity examples of all ecosystem types, and all examples of at-risk ecosystem types. The EcoObs (Ecological Observations) database manages basic site information, rapid and intensive plot data on vegetation, soils, and hydrology, and information on indicators and metrics, including floristic quality indices (Faber-Langendoen et al. 2016c). Biotics 5 is an integrated, web-enabled platform that provides the framework for managing the classification information on ecosystems, as well as plants and animals. Biotics 5 is also used to map locations of the known ecosystem locations with practical conservation value, known as "element occurrences," as well as current and potential conservation sites, and areas of land under protective management. Used by members of the NatureServe network, the system provides built-in support for our shared methodology and data standards.

The Role of Ecological Integrity in Other Assessments

Finally, although assessing the ecological integrity of an ecosystem can be the primary goal, in other cases, such assessments can be one component of a more complex ecosystem assessment. We highlight four such cases (Fig. 8).

Ecosystem Services

Understanding the services that an ecosystem provides depends in part on understanding its ecological integrity (in the past ecosystems services were sometimes called ecological functions). The classic four categories used to assess ecosystem services include a) sustaining services, b) provisioning services, c) regulating services, and d) cultural services. The sustaining services category is essentially a conceptual model of ecological integrity. Understanding the linkage between sustaining services, and thus ecological integrity, and the other services is critical to ensuring that ecosystems remain resilient, i.e., they persist through changes and disturbances caused by both natural disturbances and human resource use.

Climate Change

Every place on Earth now faces changes in the magnitude, timing, frequency, and duration of climate-driven conditions, from changes in seasonal air temperatures and weather patterns to changes in the temperature and pH of our oceans. These shifts may create climatic environments that are outside any known range of natural variation (“novel climates” of Williams et al. 2007). Thus measures of ecological integrity can contribute to our understanding of the ability of ecosystems to “adapt” to changes as climate shifts, coupled with major land use changes and the spread of invasive species. This does not make the past and current states irrelevant; rather, as Millar et al. (2007) note: “Historical ecology becomes ever more important for informing us about environmental dynamics and ecosystem response to change.”

To that end, NatureServe’s Habitat Climate Change Vulnerability Index includes 3 major components – Sensitivity, Adaptability (which together define Resilience), and Exposure (see Comer et al. 2012). For ecosystems, the indicators for the sensitivity component are essentially equivalent to those of ecological integrity. Thus our assessment of ecological integrity will inform how ecosystems respond to climate change.

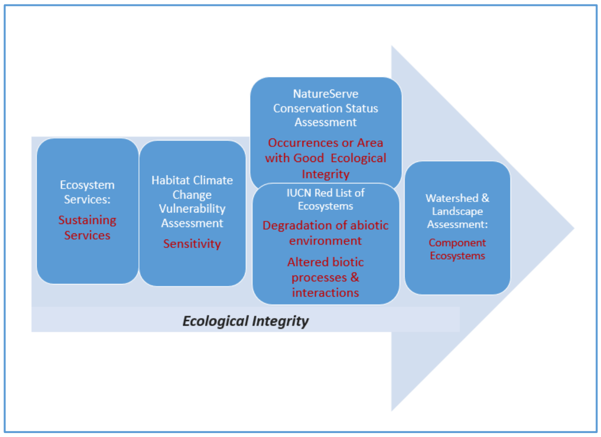


Figure 8. Ecological integrity concepts contribute to a variety of other assessment methods. Each criteria or factor in red requires information on ecological integrity of the ecosystem. Other assessment methods include a) Ecosystem Services, b) Habitat Climate Change Vulnerability Assessment (HCCVI), (Comer et al. 2016), c) ecosystems at risk, for both the NatureServe Conservation Status Assessment (Master et al. 2012) and the IUCN Red List of Ecosystems (Keith et al. 2013), and d) Watershed and Landscape Assessments. See text for details.

Ecosystems At Risk

As the world's biodiversity continues to decline, conservationists have recognized that we need to evaluate not just the species that are most at risk, but also the ecosystems they depend on. The challenge of developing such methods is great, given the complexity and diversity of ecosystems. But the information already gained from understanding the ecological integrity of ecosystems will be of great help. That is, a well-developed conceptual ecological model, with key attributes, indicators, and assessment points, provides some of the key information needed to assess the potential for ecosystem collapse.

For that reason, the two major methods that are used in North America – NatureServe's Conservation Status Assessment (Master et al. 2012) and the IUCN Red List of Ecosystems (Keith et al. 2013) – incorporate knowledge of ecological integrity into the assessment process. NatureServe's method contains a rank factor called "Number of Occurrences or Percent Area with Good Ecological Integrity." Two of the five IUCN criteria are based largely on ecological integrity: Criterion C, "Degradation of Abiotic Environment" and Criterion D, "Altered Biotic Processes and Interactions."

Watershed and Landscape Assessments

By-and-large, the EIA methods discussed here focus on the ecosystem as the target of evaluation, whether broadly defined (all forests, wetlands) or finely defined (red spruce forest, Midwest prairie fen). But it is also necessary to address the condition of entire watersheds and landscapes. An assessment of the ecological integrity of the component ecosystems can be integrated into these assessments, even as new indicators are needed to track issues of fragmentation, representativeness, and other functions at these larger scales. Examples of the integration of site-based EIAs with watershed and landscape assessments include that of Vermont (Sorenson et al. 2015, Sorenson pers. comm. 2016). From a conservation and resource management perspective, the integration of site-based ecological integrity assessments with landscape and watershed-based assessments is a worthy pursuit, because it will be the best way to maintain ecosystem services, prevent ecosystems from becoming at risk, and ensure their persistence in the face of climate change.

Conclusion

NatureServe's EIA methodology provides a succinct assessment of the current status of the composition, structure, processes, and connectivity of a particular occurrence of an ecosystem type. Our method uses a metrics-based approach, guided by conceptual models, reference conditions, and natural ranges of variation. It can be applied using remote sensing (Level 1), rapid field-based (Level 2) or intensive field-based (Level 3) metrics to individual sites or across watershed, landscapes, regions and states. NatureServe and Network programs, in partnership with private, state and federal agencies and organizations, are applying the methodology to guide our understanding of ecosystem condition across a wide range of ecosystem types, such as bogs, salt marshes, temperate rainforests and grasslands. By improving our understanding of ecological integrity, we provide the critical information needed to maintain and restore natural ecosystem processes, and the species and services that depend on those ecosystems.

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For this EPA funded project, which ran from 2013-2016, each of us were already involved in developing EIAs for our programs, and so we came together to form a core team that would reevaluate and test the methodology. Our work is summarized in Faber-Langendoen et al. (2016). We also invited other states to peer review work before final submission. We thank Josh Cohen (Michigan), Sandy Crystal (New Hampshire Department of Environmental Services), Andy Cutko (Maine Natural Heritage Program), Ron Hellmich (Indiana), and Este Muldavin (New Mexico Natural Heritage Program) for their timely reviews. We also thank Tom Foti (Arkansas Natural Heritage Program) for his review as part of his overall work on ecological integrity indicators for all ecosystem types in Arkansas.

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APPENDICES

Appendix A. Evaluation form used for draft list of indicators for Gulf Coast ecosystems (Goodin et al. 2016 draft). Criteria can be scored using a rating scale, such as: 1=minimally effective, 2=less effective, 3=moderately effective, 4=more effective, 5=extremely effective. Comments may be added to each rating. Adapted from Herrick et al. (2010).

	Evaluation Criteria	**Criteria Definition**
Ecologically Relevant	Informative of ecological condition	Ecologically relevant and can be used to assess current ecological condition. Reference values (i.e., the value or range of values expected for a site when it is at its ecological potential) exist.
	Applicable at multiple scales	Applicable to management at multiple scales (plot to Gulf-wide). Characterization of indicator at one scale can be extrapolated to other scales (assuming an appropriate sampling design) in order to facilitate interpretation of current condition or provision of services.
Feasible	Low Cost for data collection	Cost, including field and analysis expense and time, necessary to obtain the required number of measurements with a sufficient level of precision, accuracy and repeatability (across years) is relatively low.
	Currently collected in the Gulf	Currently collected in the Gulf by existing monitoring programs.
	Can be collected more cheaply by remote sensing	Remote sensing detection currently or soon possible at less than field cost at observation level with high resolution imagery or satellite imagery.
Response Variability (statistically sound)	Detects Long Term Trends	High signal:noise ratio (sensitive to detecting long-term trends and insensitive to short-term variability, such as differences associated with short-term weather patterns and time since disturbance).
	Repeatable	Can be measured with a methodology that provides consistent results by different observers. Low susceptibility to bias. Relatively easy to standardize measurement or observation of indicator across observers.
Management	Precision suitable for analyses that support management applications	Can be quantified with selected sampling design with sufficient level of precision at scale(s) relevant to management needs.
	Applicable to multiple management objectives	Can be consistently applied to address multiple management objectives including LMRs
	Can be easily explained to and applied by managers	Can be applied by trained mangers with undergraduate or master's level knowledge of relevant resource management. Does not require specialized expertise to apply.