NPS Interim Technical Guidance on Defining Meaningful Desired Conditions for Natural Resources
APPENDIX C.

Identifying Metrics and Assess Ecological Integrity Measures

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To assess ecological integrity values for a resource, a framework to identify metrics and measures is necessary. Steps for specialists to assess measures on resources from the NPS Ecological Integrity Assessment Framework (EIAF) are presented here. While a single specialist may be assigned these tasks, they are realistically achieved by a multidisciplinary assessment team. Multidisciplinary means expertise from multiple resource and scientific disciplines, not from multiple administrative programs.

Once focal resources are selected (as discussed in the Interim Guide on Defining Desired Conditions and the EIAF), several steps should be taken to develop metrics and measures. While some of these may be obvious, going through these steps will act as a reminder for issues that a specialist may have missed.

Key Ecological Attributes

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

Key ecological attributes of a resource include:

- Critical or dominant characteristics of the resource, such as specific characteristics of: (a) demographic or taxonomic composition; (b) functional composition; (c) spatial structure; (d) range or extent; and

- Critical biological and ecological processes and characteristics of the environment that: (a) limit the regional or local spatial distribution of the resource; (b) exert pivotal causal influence on other characteristics; (c) drive temporal variation in the resource's structure, composition, and distribution; (d) contribute significantly to the ability of the resource to resist change in the face of environmental disturbances or to recover following a disturbance; or (e) Determine the sensitivity of the resource to human impacts.

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

"*Size*" refers to attributes related to the numerical size and/or geographic extent of the focal resource. Examples include the size of a population of a species, the number of viable sub-populations, or the area within which a particular ecological system occurs.

"*Condition*" refers to attributes related to biological composition, reproduction and health, and succession; critical ecological processes affecting biological structure, composition and interactions; and physical environmental features and dynamics within the geographic scope of the focal resource. Examples include species composition and variation, and patch and succession dynamics in ecological systems, and locally generated disturbance regimes that trigger these dynamics.

"*Landscape Context*" refers both to the spatial structure (spatial patterning and connectivity) of the landscape within which the focal resource occurs; and to critical processes and environmental features that affect the focal resource from beyond its immediate geographic scope. Examples of the former group include attributes of fragmentation, patchiness, and proximity or connectivity among habitats. Examples of the latter group include connectivity between, and movements of matter and energy between a focal ecological system and surrounding systems; and regional or larger-scale disturbances.

Importantly, key ecological attributes are not simply those characteristics of a focal resource that are threatened by human interference or that are amenable to direct conservation management. Rather, key ecological attributes provide a picture of how the resource *should* be and how it *should* function in the absence of significant human intrusion. They direct attention to those critical aspects of a resource that are impaired and require restoration, *and* those that currently lie within their acceptable ranges and need to be kept there. Table 1 provides examples of the types of key ecological attributes frequently identified for terrestrial (e.g., forested) and riverine ecological systems.

Table 1. Common Types of Key Ecological Attributes for Terrestrial and Riverine Ecological Systems.

Terrestrial Ecosystem	**Riverine Ecosystem**
<u>*Environmental Disturbance Regimes*</u> ▪ Fire area/intensity regime ▪ Wind disturbance regime ▪ Precipitation & flooding extremes ▪ Air temperature extremes ▪ Geologic disturbances	<u>*Channel Morphology & Sediments*</u> ▪ Channel erosion-deposition, stability-instability ▪ Channel shape, macrohabitat sequencing Bed/bank porosity & texture ▪ Bed/bank sediment chemistry

▪ Air quality, cloudiness	▪ Coarse organic matter
Connectivity ▪ Connectivity with adjacent systems (terrestrial, aquatic) ▪ Connectivity among similar & different patch types within target system	*Connectivity* ▪ Drainage/flow-path connectivity ▪ Flood-zone inundation-recession connectivity ▪ Surface-groundwater connectivity ▪ Riparian corridor continuity ▪ Riparian corridor-upland connectivity
Hydrology ▪ Precipitation (rain, snow, fog) ▪ Soil moisture ▪ Surface water - groundwater exchange ▪ Snow/ice cover ▪ Freeze/thaw	*Hydrology* ▪ Surface water flow regime ▪ Surface water elevation ▪ Surface/groundwater exchange ▪ Ice cover & transport ▪ Spatial extent of disturbances
Soils Chemistry & Structure ▪ Soil chemistry (organic content, nutrients, other chemicals, gases, salinity) ▪ Soil temperature & pH ▪ Soil structure & drainage ▪ Soil erosion & deposition	*Hydrochemistry* ▪ Water chemistry (ions, compounds, gases, salinity) ▪ Water temperature & pH ▪ Particulate & dissolved organic matter ▪ Water turbidity/clarity ▪ Plant litter & mineral inputs ▪ Solar and geothermal inputs
Biotic Interactions, Composition, Structure ▪ Keystone species and/or functional groups ▪ Rare/sensitive species or species groups ▪ Food web structure (guilds) ▪ Component communities & seral stages ▪ Spatial arrangement of key species & communities ▪ Migration-aggregation-dispersion ▪ Vegetation stratification & structure within patches ▪ Infestations & mass grazing ▪ Seed bank dynamics	*Biotic Interactions, Composition, Structure* ▪ Keystone species and/or functional groups ▪ Rare/sensitive species or species groups ▪ Food web structure (guilds) ▪ Component communities & seral stages ▪ Spatial arrangement of key species & communities ▪ Migration-aggregation-dispersion ▪ Infestations & mass grazing

A hierarchical approach to identifying attributes can help managers initiate the identification of KEAs, as presented in Table 2 (Young and Sanzone 2002):

Table 2 Ecological Attributes

Landscape Condition • Extent of Ecological System/Habitat Types • Landscape Composition • Landscape Pattern and Structure	**Chemical and Physical Characteristics Ecological Processes** • Energy Flow - Primary Production - Net Ecosystem Production - Growth Efficiency • Material Flow - Organic Carbon Cycling - Nitrogen and Phosphorus Cycling - Other Nutrient Cycling
Biotic Condition • Ecosystems and Communities - Community Extent - Community Composition - Trophic Structure - Community Dynamics - Physical Structure • Species and Populations - Population Size - Genetic Diversity - Population Structure - Population Dynamics - Habitat Suitability • Organism Condition - Physiological Status - Symptoms of Disease or Trauma - Signs of Disease	**Chemical and Physical Characteristics Hydrology and Geomorphology** • Surface and Groundwater Flows - Pattern of Surface Flows - Hydrodynamics - Pattern of Groundwater Flows - Salinity Patterns - Water Storage • Dynamic Structural Characteristics - Channel/Shoreline Morphology, Complexity - Distribution/Extent of Connected Floodplain - Aquatic Physical Habitat Complexity • Sediment and Material Transport - Sediment Supply/Movement - Particle Size Distribution Patterns - Other Material Flux
Chemical and Physical Characteristics (Water, Air, Soil, and Sediment) • Nutrient Concentrations - Nitrogen - Phosphorus - Other Nutrients • Trace Inorganic and Organic Chemicals - Metals - Other Trace Elements - Organic Compounds • Other Chemical Parameters	**Natural Disturbance Regimes** • Frequency • Intensity • Extent • Timing • Duration

- pH - Dissolved Oxygen - Salinity - Organic Matter • Physical Parameters	

Identifying the key ecological attributes for each focal resource involves an iterative process, in which specialists build a list of candidates and refines this list to a final version. Identifying the key ecological attributes for a focal resource requires creative thinking. For example, the information available about any particular focal resource may not be organized neatly in terms of key ecological attributes. It can take some careful and insightful thinking to extract the needed information.

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

The following six questions guide the process of identifying key ecological attributes.

1) **To what extent does the <u>size or spatial extent</u> of the focal resource matter, in order for the resource to persist over the long-term (decades to centuries)?**

- Every *population of a species* selected as a focal resource must be large enough to recover following disturbances as well as to participate in critical ecological processes. For example, a species may fill an ecological role as a top predator, as a shaper of the physical landscape, or as a migrator sensitive to landscape or waterscape connectivity. The spatial extent of the population or meta-population within the project area, the density of occurrences of sub-populations, and other aspects of size may also matter.

- Similarly, every *ecological community* or *ecological system* selected as a focal resource may need to occur across some minimal area, in order to recover following disturbances or sustain critical ecological processes. For example, natural disturbances and successional dynamics across a grassland ecosystem may promote the presence of a wide range of species and communities. The ability of the grassland to support this ecological diversity often depends upon its size.

2) **What are the most important <u>biological characteristics</u> of the focal resource that need to be sustained over the long-term?**

- Every *population* of a species selected as a focal resource will possess certain characteristics that are necessary for its survival. These will always include aspects of the species' life history necessary for the population to persist, and aspects of population structure and distribution necessary for population persistence.

- Every *ecological community* or *ecological system* selected as a focal resource will also possess certain biological characteristics necessary for its persistence. These will include the mix of species whose interactions define and sustain the focal resource or characterize successional gradients; and critical patterns of relative species abundance and spatial distribution among these species that shape these interactions.

- Examples of such key biological characteristics to consider for a *population* include genetic composition, demographic (age, gender) composition, and abundance. Examples of such biological characteristics to consider for a focal *community or ecological system* include taxonomic composition with emphasis on dominant, characteristic or rare/imperiled taxa; functional composition, including feeding or breeding groups or guilds, or keystone taxa; demographic composition; community or seral stage composition; and spatial relationships (horizontal, vertical) among taxa, functional groups or seral stages.

3) **What are the most important <u>biological processes</u> that must occur for the focal resource to persist over the long-term?**

- Every *species* selected as a focal resource will exhibit certain patterns of interaction among members of its population(s), and between its population(s) and other species that significantly shape the size, biological composition, and distribution of its population(s) over space and time.

- Every *ecological community* or *ecological system* selected as a focal resource will also exhibit certain patterns of interaction among its member species that significantly shape the extent and biological composition of the focal resource and its spatial structure over space and time.

- Examples of such critical processes to consider for a focal *species* include genetic isolation, mutation, or hybridization; aggregation, dispersion, or migration; recruitment or mortality; health dynamics; and seed-bank persistence.

- Examples of such critical processes to consider for a focal *community or ecological system* include competition, exclusion, or succession; predation or herbivory; parasite, pathogen, or infestation dynamics; mutualism among species (e.g., pollination); multi-species aggregation/dispersion or migration; productivity; trophic dynamics or nutrient cycling; and biological transformations of physical or chemical habitat.

4) **What are the most important <u>environmental regimes and constraints</u> that must occur (or be absent) or fall within some specific range of variation for the focal resource to persist over the long-term?**

- Every *species* selected as a focal resource will have evolved adaptations to specific physical environmental conditions, within which it can grow and reproduce, avoid excessive mortality from its interactions with other species, and avoid or survive exposure to harmful environmental extremes and disturbances. These conditions may include relatively dynamic environmental features such as weather, hydrologic, and fire regimes; and relatively static features of geology and topography. The absence of some condition may be as important as the presence of others.

- Every *ecological community* or *ecological system* selected as a focal resource similarly will have evolved in a specific type of environmental setting, characterized by specific physical environmental conditions and their patterns of variation, within which its member species can reproduce and interact, avoid excessive mortality from their interactions with each other, and avoid or survive exposure to harmful physical environmental extremes and disturbances.

- Examples of such key environmental regimes and constraints to consider for a focal *species, community or ecological system* include the fire regime; hydrologic regime (surface, groundwater; watershed, waterbody; freshwater, coastal); current or tidal regime (freshwater, coastal, marine); temperature regime (air, water, soils); precipitation, cloud/fog, or humidity regime; snow/ice cover or freeze/thaw regime; water/air clarity regime; air/water/soil chemistry regime; geomorphology/geomorphic regime; topography/bathymetry & their dynamics; and soil structure and dynamics. Where appropriate, it may be useful to consider both "normal" dynamics and extreme events/disturbances.

5) **What are the most important aspects of <u>landscape structure</u> that must be present for the focal resource to persist over the long-term?**

- Every *species* selected as a focal resource will have evolved adaptations to specific features of its habitat that must occur within some <u>spatial proximity</u> to each other, for the species to grow and reproduce, avoid excessive mortality from its interactions with other species, and avoid or survive exposure to harmful environmental extremes and disturbances.

- The environmental and biological conditions of every natural landscape or waterscape occur in particular spatial relationships to each other, established by the natural interactions of environmental regimes with the local geology and topography and by the natural interactions of species and communities. These spatial relationships shape the potential for energy and physical matter (e.g., water, sediment, light, or fire), plants and animals, eggs and spores, and seeds and other propagules to move from one part of the landscape or waterscape to another. Some of this movement may be crucial to the persistence of a species, community, or ecological system of concern. Additionally, these spatial relationships establish the level of heterogeneity in habitat conditions available, shaping the diversity of species and communities that may occur. As a result, the features of landscape or waterscape structure that shape biological movement and habitat heterogeneity may be key ecological attributes for a focal resource.

- Examples of such key aspects of landscape structure to consider for a focal *species, community or ecological system* include habitat patch shape and overall density; habitat proximity, heterogeneity at varying scales; watershed drainage connectivity among aquatic/wetland habitats; marine/tidal current connectivity or continuity; freshwater/coastal (including tidal) inundation-recession connectivity; animal travel habitat (corridor) continuity; proximity among corridor habitats, refugia; propagule transport pathway continuity; proximity among plant habitats, refugia; and connectivity between, proximity among adjacent communities or ecological systems.

6) **Does the focal resource contain any secondary or <u>nested resources</u>, the characteristics or requirements of which constitute key ecological attributes for the larger resource?**

- A *species* selected as a focal resource may include several sub-populations or genetic stocks within the project area, the relative sizes or distributions of which may affect the viability of the species as a whole in the project area. Different life-stages of the species may also have different habitat requirements or be susceptible to different environmental conditions. Looking at this finer biological scale – answering the aforementioned five questions for these sub-populations or life-history stages – may suggest additional potential key ecological attributes for the resource overall.

- Every *ecological community* or *ecological system* selected as a focal resource will include finer-scale communities and individual species, whose requirements must be met for them to persist within the larger community or system. The persistence and viability of these nested communities and species may be crucial to the integrity and viability of the larger resource. Answering the aforementioned five questions for such nested communities and species may suggest additional potential key ecological attributes for the larger resource.

There is no rule for the "best" number of key ecological attributes for an individual focal resource. An overly long list will result in an overly complicated model with which to guide management and monitoring. Conversely, an overly short list could miss something crucial. Instead, the final list should focus attention on those potential key ecological attributes that are the most defining, most critical or pivotal to the persistence of the focal resource and its natural internal dynamics, and that most directly affect the resource.

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

Recognized threats to a focal resource also provide crucial information for the identification of key ecological attributes. Threats to a focal resource are human activities, structures, or institutions – or consequences of these – that could cause or have caused stress to the resource. Such stress must necessarily involve the alteration of one or several key ecological attributes beyond their acceptable ranges of variation. Consequently, knowledge of how specific human actions cause harm to a focal resource will provide crucial insights into the resource's key ecological attributes. However, the list of key ecological attributes for a focal resource should include more than those simply known or anticipated to be degraded, threatened, or amenable to management; the list should be comprehensive.

Indicators

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

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

- A specific, measurable characteristic of the key ecological attribute, such as the total number of adults in a population;
- A collection of such characteristics combined into a "multi-metric" index, such as a multi-species index of forest canopy composition; or

- A measurable effect of the key ecological attribute, such as a ratio of the frequencies of two common taxa of aquatic insects (the indicator) that varies with changes in average Nitrate concentration (the key attribute) in a stream.

Indicators are selected to meet eight criteria. Indicators must be:

1. Specific: unambiguously associated with the key ecological attribute of concern and not significantly affected by other factors.

2. Measurable: measurable by some procedure that produces reliable, repeatable, accurate information.

3. Sensitive: able to detect changes that matter to the persistence of the focal resource (see discussion of thresholds and acceptable ranges of variation, below).

4. Comprehensive: able to detect changes across the entire potential range of variation in the key ecological attribute, from best to worst condition.

5. Timely: able to detect change in the key ecological attribute quickly enough that project managers can make timely decisions on conservation actions.

6. Technically feasible: amenable to implementation with existing technologies without great conceptual or technological innovation.

7. Cost-effective: able to provide more or better information per unit cost than the alternatives.

8. Partner-based: compatible with the practices of key partner institutions in the conservation effort, or based on measurements they can or already do collect.

It may not always be possible to identify a single indicator for an individual key ecological attribute that meets all eight criteria, particularly the first six, scientific criteria. In such cases, the project should use several indicators together to obtain a more reliable or more complete picture of what is going on. For example, field surveys and analyses of aerial photographs together may provide complementary information on forest tree composition that is more accurate and reliable than either indicator on its own. Further discussions, below, show how to combine information from multiple indicators into a unified assessment for an individual key ecological attribute.

Table 3 provides examples of key ecological attributes and their potential indicators for a hypothetical riparian forest community.

Table 3. Example of indicator selection for the key ecological attributes of a hypothetical riparian forest community.		
Summary Integrity Factor	**Key Ecological Attribute**	**Indicator**
Landscape Context	Landscape Composition	Edge ratio of natural/non-natural habitat (buffer)
	Landscape Structure	Connectivity to upstream and downstream communities
		Distance to nearest road or other infrastructure
Condition	Community Structure	Canopy structure index
		Mean canopy age
	Community Composition	Percent cover of native plant species
		Presence of exotic plants or weedy natives
	Energy/Material Flow	Extent and severity of surface disturbance
	Hydrology	River hydrologic regime integrity (index)
		Water table depth
Size	Area	Size relative to other occurrences
		Size proportional to historic extent of patch

Specialists must consider three broad categories of indicators, representing three levels of intensity in data collection (Brooks et al. 2004, Tiner 2004, USEPA 2006): Remote Assessment, Rapid Assessment, and Intensive Assessment. Remote-assessment indicators rely primarily on Geographic Information Systems (GIS) and remotely sensed information, as the name indicates. Rapid-assessment indicators typically involve combinations of information from remote sensing and rapid field assessment. Expert field judgment may play a strong role in this level of assessment, for example in the use of field-based visual assessment methods (Fennessey et al. 2007). Intensive-assessment indicators typically require field-based assessments or sample collection, often include quantifiable field measurement, and may include laboratory measurement of samples returned from the field. Considerations of field sample design become most relevant with intensive-assessment indicators.

The choice of which level of indicator to use for each type of key ecological attribute will depend on the need to meet the eight criteria set forth above. For example, in some cases remote assessment can meet all eight criteria and thereby satisfy all management needs for a given key attribute.

The information consulted to identify key ecological attributes for each focal resource will also provide crucial information on potential indicators for these attributes. As with the identification of key ecological attributes, the identification of indicators involves an iterative process, in which the project team builds a list of candidates and refines this list to a final version. In this case, however, the list must also be informed by knowledge of past and current monitoring and research activities in and surrounding the project area; and knowledge of monitoring practices and technologies in general.

Indicators provide reliable information on key ecological attributes only when incorporated into an actual monitoring program, following methods that ensure accuracy and representativeness and that can be repeated or sustained to provide consistent, long-term data. For this reason, decisions on indicators must also be informed by knowledge of the resources that may be required to initiate and/or sustain a long-term monitoring program.

Indicators differ from each other in the level of detail and precision that they can provide. Four types of indicators cover the spectrum of detail and precision; each can have a place in a successful monitoring program:

- **Expert Knowledge** indicators consist of information provided by experienced, reliable observers but without any formal protocol for recording and quality-checking the information. The experts may be trained professionals, volunteers or members of a traditional community that have reason to take note of the conditions of interest and the experience necessary to provide reliable information.

- **Remote Assessment** indicators consist of information derived from GIS, aerial imagery and remote sensing data. Typically the data will provide information on land cover, land use, infrastructure, and other features of the landscape and waterscape that can be mapped using remote recording technologies.

- **Rapid Assessment** indicators consist of information collected *in situ* using relatively simple field methods, including visual and auditory assessment. These methods incorporate standard protocols, field records and quality control procedures; and typically provide information on the presence/absence of specific features of a location or a focal resource, or on the relative status of specific features.

- **Intensive Assessment** indicators consist of information collected using relatively detailed, quantitative field methods. These methods may include plot and transect measurements and the use of recording sensors such as stream gauges, meteorological stations, acoustic and photographic recorders, and hydrographic sondes.

Expert Knowledge will vary in its accuracy, but it may be the only source of information at the start of a monitoring effort. Remote Assessment indicators may require field calibration and will vary in their spatial resolution as well as in their availability for different places and dates and/or the cost of procuring the data. Rapid and Intensive Assessment methods will vary in their cost and accuracy and will often provide data on only limited numbers of locations or specific monitoring dates. In general, however, the more crucial it is to monitor a particular key ecological attribute, the more important it will be to use the more data-intensive types of indicators. Expert Knowledge will at least get a project started but can not support ongoing conservation management. Remote Assessment and Rapid Assessment indicators may be sufficient for many purposes, but some management purposes will require the use of Intensive Assessment indicators as well.

It is often be necessary to decide whether some characteristic of a focal resource is a key ecological attribute by itself or merely one among several indicators needed to assess some larger key attribute. The correct decision will depend on whether the characteristic of concern should have "veto" power over the rating of the status of a focal resource. As described above, a key ecological attribute is a characteristic of a focal resource that is so important to the viability of the resource, that this viability is put into jeopardy whenever this characteristic lies outside its acceptable range of variation. If some characteristic in question has such importance, then it is a key ecological attribute and not a contributing indicator.he following rules should guide the selection of one or more indicators for each key ecological attribute:

- *Select at least one indicator for every key ecological attribute*. Managing a focal resource effectively requires reliable information on <u>every</u> key ecological attribute.

- *Choose indicators that meet as many of the aforementioned eight criteria as possible*. It is best to identify those that satisfy the scientific criteria first, and then use the institutional criteria to refine the selection.

- *Choose different types of indicators to meet different management needs*. The greater the need to manage a specific key ecological attribute – for example, to abate an active threat or provide an early warning of unwanted change – the greater the need for indicator certainty and precision. Remote Assessment and especially Expert Knowledge indicators provide less detailed and less quickly responsive information than Rapid Assessment and especially Intensive Assessment indicators. For example, a rapid assessment of wetland condition may be good enough for routine tracking, but not as effective as plot-based measurements for detecting changes in vegetation associated with a change in hydrology.

- *Incorporate indicators used by other stakeholders whenever possible*. They may not cover everything, but using them will help you meet both scientific and strategic needs without duplicating effort or expending additional resources.

- *Consider building indicators around nested biological resources*. Natural community and ecological systems selected as focal resources will often include other biological resources, consisting of finer-scale communities and individual species. Some of these nested resources may be especially sensitive to shifts in particular key ecological attributes, or may occur only in highly undisturbed settings. Their status therefore can serve as – or contribute to – indicators of the status of the overarching focal resource. For example, a species of freshwater mussel may be listed as a nested resource for a lowland river community selected as a focal resource. The mussel species may be particularly sensitive to changes in water temperature, and therefore may provide an indicator of the integrity of the water temperature regime for the overarching river community resource.

- *Consider building indicators around specific life stages of individual species.* Individual species – whether full-fledged focal resources or nested in more encompassing resources – may have particular life-history requirements that are more sensitive to changes in specific aspects of their larger environments and ecological settings than the population as a whole. For example, juvenile freshwater mussels may be more sensitive to high levels of nutrients and sediment than the adult mussels in a stream community selected as a focal resource. The status of such sensitive life stages may therefore serve as – or contribute to – indicators of the status of the species overall.

- *Never choose the same indicator to provide information on more than one key ecological attribute for any single focal resource*. Otherwise, the project will have no way to assess the distinct status of each of the key ecological attributes involved.[1]

- *Whenever possible, choose biotic indicators for key biotic attributes, and abiotic indicators for key abiotic attributes*. There are two reasons for this: First, biotic indicators tend to respond to the effects of multiple abiotic factors, while a single abiotic factor may affect multiple key biotic attributes at the same time. For example, consider the case of a desert scrub forest system selected as a focal resource, for which the compositions of the plant, insect, and bird species assemblages provide indicators of its overall biotic composition. Each of these indicators will vary in response to changes in several physical environmental regimes, such as the summer rainfall and winter temperature regimes; and each such regime will affect each indicator in a different way. As a result, no single biotic indicator can provide information about any single abiotic factor or *vice versa*. Second, biotic conditions often serve well as "lagging" indicators, while abiotic conditions more often provide "leading" information of the status of a focal resource. Both kinds of information are useful.

- *When no single indicator can span the full range of expected variation in the key ecological attribute, consider using a multi-metric indicator*. Box 6 provides an example of a multi-metric index used to assess the integrity of fish assemblages in stream systems. Such multi-metric indicators combine indicators that each respond to different but overlapping portions of the full range of expected variation in the key ecological

[1] However, some monitoring methods can generate data useful for examining *more than one indicator*, even for the same target, providing a highly cost-effective opportunity. For example, a continuous river flow gauge can provide data on indicators for several different components of the annual flow regime.

Acceptable Range of Variation

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

The natural variation in the physical environment and the interactions among species together create a dynamic "template" that determines which species from the regional pool of species may (or may not) persist in a given area. This template is the stage on which species evolve. The natural variation in this template is thus essential to maintaining biodiversity.[2][1] We use one or more key ecological attributes to describe this template for each resource value, and recognize the natural variation in each key ecological attribute as a crucial feature of the template.

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

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

Human activity has thoroughly transformed many places throughout the world, and no place is free of human impacts (Hunter 1996). Much as a changing climate throughout the Holocene (past 12,000 years) brought about changes in many of aspects of ecosystems, and resulted in many patterns of species composition we see today, so too have certain human activities shaped ecosystems. Humans have brought about large-scale and long-term changes in ecosystems even far from our farms and cities, for example through hunting and selective tree removal, releasing non-native species, augmenting lightning-strike fire regimes, and diverting streams. In many instances where the rate and magnitude of human-induced change may be limited, we can safely subsume their effects within a practical 'natural' range of variation. That is, we can assume that their effects have had only a limited impact on the evolutionary environment of biodiversity. However, often we *can* detect human effects causing rapid and substantial ecological change. And we can do so not only in recent, better documented times but in the more distant past, for example from records of ancient land clearing for corn production, desert stream diversions, or the draining of arable swamplands. When we can detect such more significant human effects, we need to presume them to be outside of some practical, ecologically functional range of variation (i.e., likely resulting in local extinctions and other biodiversity impacts).

Human activities unfortunately have changed the greenhouse gas composition of Earth's atmosphere, resulting in global changes in climate beyond the range expected from natural causes. As a result, almost every place on Earth faces changes in the magnitude, timing, frequency, and duration of atmosphere-driven conditions – from changes in seasonal temperatures and weather patterns to changes in the temperature and pH of our oceans – potentially outside the range of historic variation. The ecosystems of tomorrow in every region potentially will experience ranges of variation in atmosphere-driven conditions far different than have the ecosystems in these regions even in the recent past.

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

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

The Ecological Integrity Assessment Framework posits that *critical thresholds* exist in the range of potential variation for each key ecological attribute, for each focal resource. These are thresholds, outside of which you would anticipate – or sometimes may already observe – signs of unacceptable change or degradation to the resource of concern. For species populations, such unacceptable alteration could involve either a decline or increase in numbers beyond the lower or upper limits of natural or historical variation. On the lower side, one would expect imminent loss of the species from the area. For example, population viability analyses incorporate knowledge of growth and demographics within a given population into a mathematical model of a population's reproduction and dispersal dynamics. The output of the model provides an estimate of the probability of persistence for that species within the study area, including an estimate of the critical lower threshold below which the species would have a very low probability of persistence. On the upper side, population viability analysis would estimate an excellent probability of future persistence, and one would expect such rapid growth that this species would begin displacing other species.

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

When working with the concept of critical thresholds, we must recognize that these critical thresholds may reflect "hard" ecological thresholds (sensu May XXXX and Hollings XXXX) where the ecological systems change irreversibly or "soft" thresholds that reflects conditions of significant management concern. Upon reaching a soft threshold, the resource may not begin to change either immediately or abruptly when a key ecological attribute crosses some critical threshold. When a key ecological attribute crosses a critical threshold, the resource may initially only lose its capacity to resist change triggered by new disturbances and/or its capacity to recover following a new disturbance. Once a resource suffers such a loss of resistance or resilience, however, it may take only a slight additional change to trigger further alteration away from its acceptable range of variation. For example, the suppression of fire in a naturally fireadapted woodland for more than a few decades could leave it vulnerable to the arrival of seeds from other nearby communities, that could lead to the replacement of the dominant tree cover by other woody species that promote changes in soils and ground-cover vegetation that attract different fauna that further transform community dynamics, and so forth. Similarly, a decline in population size or density for a species of panther below some threshold may make it significantly less able to recover following some new disturbance such as a particularly harsh drought or the spread of a virus. Alternatively, when one or more key ecological attributes for an ecological community or system cross critical thresholds, the result initially may be only the loss of a few highly sensitive or specialized species. Nevertheless, such a loss may constitute an unacceptable degradation in the ability of the resource to sustain its full spectrum of biological diversity. Additionally, the changes that ensue when a key ecological attribute passes some critical threshold may take considerable time to play out, particularly in systems with very long-lived species. Nevertheless, once set in motion, such chains of consequences may be difficult to reverse.

Practically speaking, we define categories that describe the status of a given ecological resource between any of these thresholds. Using results of measured indicators, we can assign condition ratings for assessed locations occurring on a project as (a) acceptable, (b) potential concern, or (c) imminent loss. The following definitions standardize condition ratings:

> **ACCEPTABLE –** Integrity is achieved. The resource is not significantly impacted by any factors that can be managed and does not require intensive management. The acreage also meets operational goals and objectives set out in applicable management document. These acres are considered healthy and sustainable for the foreseeable future. Only minor management practices may be required to maintain the health of this resource.
>
> **POTENTIAL CONCERN –** Managed to achieve integrity. The resource is impacted by human or other environmental factors that require management to meet goals and objectives outlined in applicable management document.
>
> **IMMINENT LOSS –** Does not achieve integrity. The resource is significantly impacted by human or other environmental factors that precludes meeting desired goals outlined in management documents. Intense management may be required to meet desired goals.

Table _ includes an example of one indicator, expressed within these categories.

Table 4. Example of an indicator that includes the ratings and their criteria.

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

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

Identifying the acceptable range of variation for each indicator may be a challenge. It requires some knowledge of the natural (e.g., historic) range of variation for all key ecological attributes and their indicators. It also typically requires knowledge from similar locations where common forms of degradation have taken place. However, one of the crucial goals of any conservation project must always be to identify critical gaps in our knowledge of the resources and find ways to fix them. Working with the acceptable range of variation provides a place to initiate management. Further, it provides an explicit method to identify the present limits of knowledge about the project area, its native biodiversity, and focal resources. Even initial approximations about the acceptable range of variation for an indicator provide hypotheses on which to begin building a program of research to improve crucial knowledge.

Our discussion up to this point has focused on the thresholds or limits that define the acceptable range of variation in the indicators for a viable resource value and its key ecological attributes.

However, there is another kind of threshold to consider – a “threshold of imminent loss.” These may be the hard thresholds.

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

It is crucial that we recognize the potential existence of a threshold of imminent loss for resource values requiring restoration. Doing so will help us determine if a resource value is at risk of failure within the immediate future (e.g., 15-25 years) as a result of the condition (or trend) of some particular key ecological attribute. More precisely, it is crucial that you know how to recognize this extreme threshold with the indicators that you have selected. You do not want to miss detecting resource values that are at risk of imminent failure. On the other hand, you do not want to undertake a massive and costly rescue effort for a resource that in fact is not at risk of such imminent failure. Unfortunately too, we may not want to expend resources on a resource for which success is too unlikely or the costs of the rescue too high to justify the effort. Decisions on rescuing species that have crossed a threshold of imminent loss – for example, the California condor, or the black-footed ferret in the U.S. – partly depend on whether we can tell if the species can be rescued, and at what cost.

Once we evaluate the natural and acceptable ranges of variation for relevant indicators, then clarify important thresholds, we are best positioned to evaluate current conditions and state the conditions we desire on site.

The information consulted to identify key ecological attributes and indicators for each focal resource will also provide crucial information on the ecologically acceptable range of variation (ARV) these indicators. Often, however, the information on historic, natural, or acceptable ranges of variation is not well codified or formally expressed in the literature, requiring some conversion.

Historical records of temporal variation for a given indicator may exist, either within the landscape of concern or elsewhere across the distribution of that focal resource. Such records may include, for example, daily, annual, or other regular periodic records of historic fish or timber harvests or records of past climate. These records may provide useful data on historic reference conditions or ranges of variation, particularly from times before some significant change in human activities in the project area. However, most such records will provide evidence for only a relatively small sample of time, usually one during which other human activities – or different climate conditions – and their legacies may have been at work. As a result, the project team will need to judge the utility of such historic records rather than assume that they provide definitive information. In fact, such potential biases may exist in all the information sources discussed here.

The historic spatial distribution of the focal resource – or the same or similar biological resources elsewhere – can provide evidence of specific limiting conditions and the thresholds at which they affect the resource. Patterns may be detected in both the overall regional distribution and local, patch-specific distributions. Most often this approach will reveal limiting physical environmental conditions, such as winter air temperature or precipitation, but can also include limiting biotic conditions such as the presence of a preferred prey, host, or habitat feature.

The immediate project area, or some other comparable area, may support relatively undisturbed examples of the focal resource for which some information is available. While this information may not indicate the limits of acceptable variation, it may nevertheless provide a set of "benchmarks" or "reference conditions" against which to compare other settings. Identifying such conditions is often crucial for establishing initial hypotheses about acceptable ranges of variation. Information from such reference settings may also provide indications of how much deviation from these benchmarks may be acceptable. (See also Footnote 3, below).

The ecological requirements of sensitive nested resources may also provide valuable information. As noted above, some of a project's focal community and ecological system resources may include nested biological resources, consisting of finer-scale communities and individual species. Some of these nested resources may be better known than the larger, encompassing resource; economically important species in particular are often better documented than other species. Nested resources therefore may provide an initial basis for estimating the acceptable ranges of variation in indicators for the overarching resource. Nested resources that are very sensitive to human impacts in particular may provide evidence of critical thresholds of degradation. For example, amphibians as a group tend to be very sensitive to slight environmental changes; and they are often well-known enough that their literature can provide useful estimates of reference conditions and ARV.

Similarly, it can be useful to look at the ecological requirements of sensitive life-stages. As also noted above, individual species may have particular life-history requirements that are strongly conditioned by specific aspects of their larger environments and ecological settings. These conditions may affect success in migration, life-stage transitions, mating, survival of particular kinds of disturbances, and so forth. Such life-history limitations may also provide evidence of specific thresholds of acceptable variation, whether the species is a full-fledged focal resource or nested in some more encompassing resource. As noted earlier, for example, juvenile freshwater mussels may be more sensitive to high levels of nutrients and sediment than the adult mussels in a stream community selected as a focal resource. In such a case, the levels of tolerance of the juvenile mussels may establish the acceptable range of variation in nutrient and sediment levels for the larger resource.

Information on critical thresholds can also be evident in the ways in which the focal resource, a nested resource, or similar species, communities, or systems respond to specific types of threats. This approach can complement an assessment of reference occurrences. A search for such information should consider a wide region, as the specific type of focal resource (or nested resource) may be better known or more heavily threatened elsewhere. For example, are thresholds evident in the ways that fire suppression, grazing, dam operations, pollution, or other type of stress have affected this type focal resource? In some cases, studies conducted to support governmental regulations may provide invaluable additional information – for example, studies in support of water quality standards, which identify maximum acceptable concentrations of specific pollutants for water bodies for which support of aquatic life is a priority.

It may also be appropriate to use information encoded in environmental regulations. National, state, and tribal laws often (and increasingly) regulate the ways in which people are allowed to alter the physical environment. Regardless of how much force such laws or their associated regulations carry, or how well governments enforce them, they may incorporate information on the acceptable levels of specific environmental factors. However, they may not be written to provide benefits for biological conservation. Many species are more sensitive to environmental contaminants or other environmental changes than are people. Water quality standards for streams and lakes, for example, often reflect concerns for human health alone, or seek to protect only some minimal biological conditions rather than the full spectrum of biodiversity of interest to you.[3]

Computer modeling or simulation can help develop estimates of critical threshold values. For example, modeling can provide estimates of the amount of fragmentation of a forested landscape that could occur before the ability of a migratory forest species to move across the landscape falls to some critical level. Two common types of modeling are Population Viability Analysis and Minimum Dynamic Area Analysis.

Regardless of the sources consulted, the resulting information may not allow the development of precise quantitative estimates of the acceptable range of variation for some indicators. As an alternative, however, it may be possible to estimate at least the degree of alteration that the focal resource can tolerate, relative to some current or historic benchmark. For example, it might be possible to estimate the limit of acceptable variation as “a 10% reduction in average annual river discharge,” “a 20% increase in the frequency of fires of intensity XX,” or “a 25% reduction in the area of forest type ZZ” relative to some reference period. These should not be arbitrary – i.e., there should be some reasons for the values – but they also should stand only as initial estimates until better data become available.

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[3] For example, U.S. federal, tribal and state water quality standards for the protection of aquatic life often rest on assessments of reference sites. A review of the information underlying the standards may therefore also lead to information on such reference sites, which may be useful on its own.

References (to be added)

Young, T. F. and S. Sanzone (2002). A Framework For Assessing and Reporting on Ecological Condition. Washington, DC, United States Environmental Protection Agency: 142.