Methods for Evaluating Ecosystem Integrity and Monitoring Ecosystem Response

February 12, 2003

Introduction

The conservation of biological diversity is recognized as an essential, albeit daunting, task for the future of life on earth (e.g., Wilson 1988, World Resources Institute 2000). In recognition of this, governments, corporations and non-profit organizations are directing substantial resources toward myriad projects designed to conserve biodiversity. However it is often not known specifically which approaches to conservation will be most effective in particular circumstances. Also resources available for such efforts are typically in short supply relative to the magnitude of the problems. For these reasons, it is imperative that there be accurate, quantifiable frameworks in place for measuring the project success (Margoluis and Salafsky 1998). Without rigorous evaluations of prior conservation actions, missteps will be repeated, with additional and/or continued ecosystem degradations being a likely consequence.

Any attempt to determine the extent to which natural resources have been conserved (or restored, in the case of restoration projects) will require some type of ecological status assessment, and, ideally, knowledge gained from such status assessments will inform subsequent conservation actions via the adaptive management process (Holling 1978, Walters 1986). To assess the status of populations at the species level, conservationists often rely on well-developed methodologies of population viability analysis (PVA, Shaffer 1981, Beissinger and McCullough 2002). Insights gained through PVA have, in certain instances, advanced conservation in dramatic ways (e.g, Crouse et al. 1987, Wooton and Bell 1992, Morris et al. 1999). However, there is no agreed upon theory, or even general scientific consensus, for how to assess the status of higher levels of biological organization, such as natural communities and ecosystems, although the importance of their conservation is well recognized (e.g., Scott et al. 1993, Poiani et al. 2000).

In the absence of a well-developed theoretical foundation, it is commonly accepted that given adequate knowledge of natural community and ecosystem structure, function and process, important and necessary initial steps may be taken to begin to solve conservation problems in need of immediate attention. Such is the case with conservation activities on the Sacramento River, where considerable emphasis has been placed on the moving conservation projects forward on the ground, even in the absence of a fully-developed framework for assessing ecological integrity and tracking ecosystem responses to management actions.

Our intent in this section of the report is to describe a new framework that TNC has developed to promote a quantitatively rigorous method of Ecological Integrity Assessment. This framework is designed to provide information needed to evaluate the effects of conservation actions in large landscape-scale projects such as that which TNC and its partners are engaged in on the Sacramento River. When properly applied the framework generates standardized methodologies and testable hypotheses and promotes the advancement and transfer of knowledge among scientists and natural resource managers. Moreover, when appropriately implemented, this methodology should translate to more effective and efficient allocation of scarce conservation resources. As we work to implement this approach on the Sacramento River, we will be coordinating with other groups that are also engaged in the development of ecosystem monitoring frameworks (e.g., The Bay Institute).

The assessment framework is based on analyses of ecological integrity (or "biodiversity health") through a limited selection of attributes that strive to (1) capture the complexity and processes required to sustain the biological diversity in question, (2) facilitate the establishment of quantitative and specific long-term conservation goals, and (3) establish a scientifically rigorous protocol that can be consistently applied across space and over time – three issues recognized as necessary in developing effective ecological indicators (Dale and Beyeler 2001).

Background

Many organizations have sought a practical framework to incorporate lessons learned from the discipline of conservation biology into conservation action, and TNC is no different (Salafsky and Margoluis 1999, Barbour et al. 1999). The Conservancy's mission is to preserve the plants, animals, and natural communities that represent the diversity of life on earth by protecting the lands and waters they need to survive. This mission is accomplished through a 4-component, science-based "Conservation Approach," which includes (1) the setting of ***priorities*** through ecoregional planning that identifies the biodiversity elements that will be the focus of conservation and determines conservation goals and areas for those elements, (2) the development of conservation ***strategies*** that will conserve that biodiversity, (3) taking direct conservation ***action*** at multiple scales, and (4) ***measures*** of conservation success to ensure that implemented strategies are effective and efficient. Woven through each of these components of the Conservation Approach are two principal objectives: (1) the maintenance or improvement of biodiversity health and (2) the abatement of critical threats to biodiversity. Achieving these objectives requires the integration of the best available ecological knowledge into the priorities, strategies, actions, and measures employed.

Methods

The assessment framework was developed from 2000-2002 by a core group of Nature Conservancy science and practitioner staff with extensive experience across the United States and Latin America in conservation planning and measurement at multiple scales. The draft framework was then tested at a large number of conservation areas (see Table 1 for a sample of test locales), and adaptively modified to seek the correct balance of rigor and practicality that would serve planning and measurement efforts at multiple scales regardless of data availability or political/institutional context. The framework was reviewed by a number of programs within The Nature Conservancy, including The Freshwater Initiative and Landscape Conservation Networks that focus on grazing, fire, and wetland conservation.

Table 1. Representative sites used for field-testing the proposed Ecological Integrity Framework.

Pilot Testing Sites	State/Region, Country
Komodo National Park	Indonesia
Cosumnes River	California, USA
Nevados de Chillán	Region 8, Chile
Greater Punta Curiñanco Conservation Area	Region 10, Chile
Neversink River	New York, USA
Great Sand Dunes Complex	Colorado, USA
Middle Fork, John Day River	Oregon, USA
Pacaya Samiria Reserve	Perú
Manitou Forest	Minnesota, USA

Results

The Ecological Integrity Framework developed by The Nature Conservancy is a framework for setting conservation goals and measures of success, and assessing the viability, or ecological integrity, of focal biodiversity at multiple scales. The framework consists of the following four components:

1. Identification of key ecological attributes that determine the composition, structure, and function of focal biodiversity.
2. Identification of measurable indicators to describe key attribute status.
3. Determination of acceptable ranges of variation for key attributes based on reference conditions, and establishment of minimum integrity threshold criteria for conservation.
4. The rating of key attribute status and assessment and monitoring of overall integrity status based on status of all key attributes.

In this framework, the concept of "key ecological attributes" is presented as the currency for identifying and measuring the composition, structure, and function of focal biodiversity at multiple (e.g., ecoregional or conservation area) scales. For each of these key attributes we propose the identification of "indicators", for describing and measuring these key attributes; and propose working with "ecological thresholds" as a consistent, scientific basis for rating the status of individual key attributes based on these indicators. Such thresholds are based on reference conditions that reflect the acceptable ranges of variation of those attributes. We also propose further means by which the rating of key attributes with respect to these thresholds can result in a categorical measurement system that is detailed in its scientific justification, yet simple, informative and compelling to any type of audience regardless of their scientific or conservation training.

Key Ecological Attributes

The framework rests on the premise that for any species, community or system there are a number of identifiable key ecological attributes that sustain the conservation target and maintain its composition, structure and function. Examples of key ecological attributes include forest canopy age structure, coral reef community composition, pollination, seed dispersal, natural hydrologic or fire regimes, tree fall gap patterns, predation and herbivory (see Box 1 and Fig. 1). The Ecological Integrity Assessment framework is based on the assumption that a significant disruption in the function of any of these key ecological attributes will degrade the integrity of that conservation target. The goal of conservation efforts should therefore be to ensure that all key attributes for the focal biodiversity are in as natural a state as possible.

The identification of key ecological attributes relies on an understanding of how conservation targets function. There are likely no conservation targets whose ecology is fully understood, and this appears to present a stumbling block to identifying key ecological attributes. Yet, for almost every conservation target there are experts who are familiar with the general composition, structure, and function of the biodiversity focal point in question, or who are familiar with a similar system from which comparisons may be drawn. Such expert knowledge can serve as the basis for moving forward with the rigorous assessment of ecological integrity. The understanding of key ecological attributes always involves developing hypothetical descriptions about what biological composition, biotic interactions, abiotic conditions, and ecological processes characterize a conservation target in its "healthiest" or most "natural" state. Even when reliable knowledge of a conservation target is limited, it is important to formulate these hypotheses with the best available information, while documenting assumptions and information gaps.

Box 1: How to Identify Key Ecological Attributes

The *Key Ecological Attributes* are those components that *most clearly define or characterize the conservation target, limit its distribution, or determine its variation over space and time, on a time scale of 100+ years.* The best way to identify such Attributes is by reviewing or developing conceptual models for the biodiversity in question. They may include:

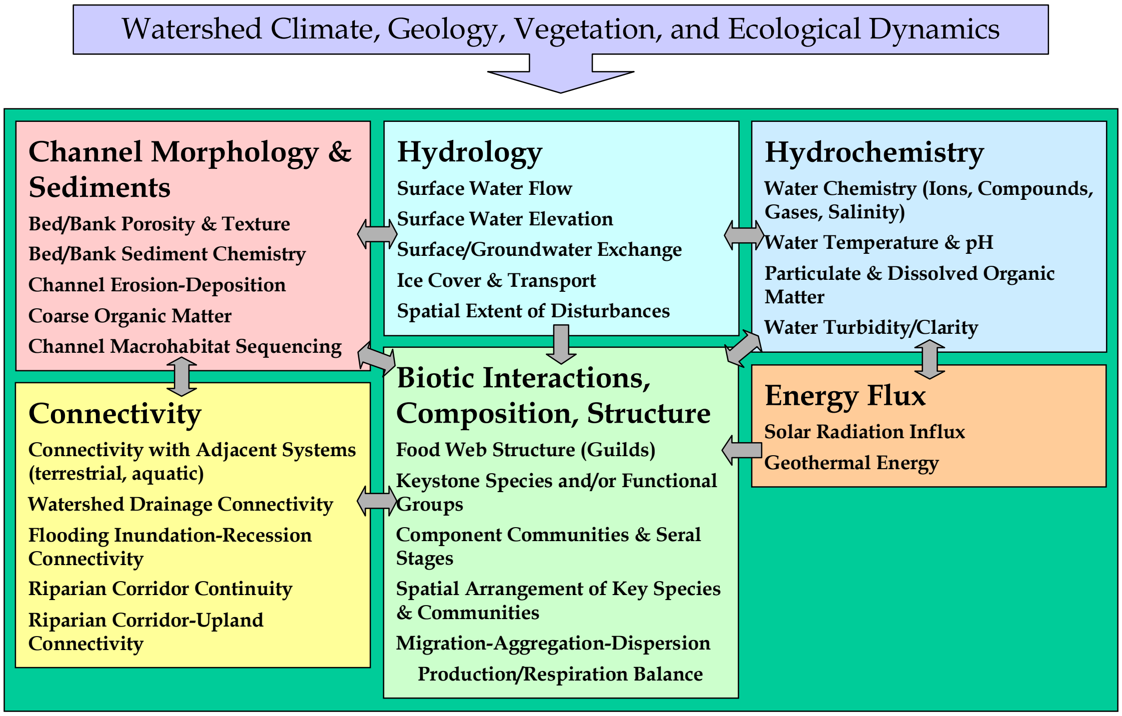
- Major characteristics of ***biological composition*** and the ***spatial structure*** of this composition, such as:
    - characteristic and keystone species, functional groups or guilds
    - population and/or community structure, including size of a minimum viable population for species targets
    - presence and distribution of characteristic species, ecological communities, or successional (seral) stages and gradients, seed banks
    - characteristic horizontal or vertical spatial relationships among size/age cohorts, species, ecological communities, or seral stages and gradients
    - species or groups of species that have significant impacts on the distribution of biomass at different trophic levels or on the physical or chemical structure of habitat.
    - primary production / respiration balance

- ***Biotic interactions*** that significantly shape or control this variation in biological composition and its spatial structure over space and time, such as:
    - food-web dynamics: levels of predation or large-scale herbivory
    - inter-specific competition and succession
    - migration, aggregation, and dispersion
    - pathogens, infestations, invasions, and other natural biological disturbances
    - pollination, aging, and reproduction

- ***Environmental regimes and constraints*** (or abiotic interactions) that significantly shape physical and chemical habitat conditions, and hence shape variation in biological composition and structure over space and time in relation to these conditions. Both extreme environmental disturbances and "normal" variation should be considered. Examples include:
- atmospheric temperature and precipitation (solar radiation influx)
- disturbance regimes
    - – minimum dynamic area of disturbance should inform size
    - – fire
    - – wind, precipitation, and flooding extremes
    - – soil erosion and accretion
    - – temperature extremes
    - – geologic events (geothermal energy)
    - – spatial extent of disturbance
- surface and ground water hydrologic regimes
    - – soil moisture
    - – groundwater elevation and surface – sub-surface exchange
    - – snow / ice cover / ice transport
    - – freeze / thaw
    - – water mixing and circulation
    - – lake level variance
    - – inflow variation (local runoff, groundwater, riverine)
    - – water flow
    - – storm event
- water and soil chemistry
    - – chemistry (nutrients, hydrocarbons, gases, salinity)
    - – temperature and pH
    - – particulate and dissolved organic matter
    - – water turbidity / clarity
- geology, topography/bathymetry, and geomorphology
    - – soil structure and drainage, porosity and texture
    - – macro / micro bathymetrics and outlet morphology
    - – coarse organic debris
    - – reef topography
    - – shoreline complexity

- ***Environmental and ecological connectivity*** that affects the ability of species and groups of species or their propagules to move or be carried (e.g., by wind or water or other biota) among suitable locations on the land- and water-scape, to maintain diversity at genetic, species, and ecological community levels. Connectivity also affects the ability of natural environmental processes to transport habitat-forming matter across the land- and water-scape, such as dissolved nutrients, soils, stream sediments, woody debris, and other organic matter. Types of connectivity to consider include:
- connectivity with adjacent systems (e.g., terrestrial / aquatic)
- intra- and inter-patch connectivity (e.g., within and between patched in a riparian corridor)

Figure 1. Typical Key Factors in Riverine Ecological System Integrity



Identifying the key ecological attributes for the focal biodiversity provides only one of the building blocks for a rigorous framework for measuring success. It is also necessary to identify the field-based indicators that can be used to measure the status of each key ecological attribute. An indicator for a key ecological attribute consists of some characteristic of that factor, or some collection of characteristics combined into an overall index, that strongly correlates with the status of that factor. Such indicators are a measurable means for obtaining information that substitutes for or summarizes what you most need to know about the key ecological attribute, when you can not directly measure the attribute itself.

Ideally, there would be a single indicator inextricably linked to the status of each key ecological attribute, that directly informs practitioners of the key ecological attribute's true state. At times, however, more than one indicator may be needed to inform conservationists of the key ecological attribute's status. In general, an economy in indicator selection (1-2 indicators per key factor) is encouraged, such that the status of all key ecological attributes can be measured in a rigorous yet sustainable and cost-effective manner over the life of a conservation project. Box 2 provides some guidelines that may be followed to aid in indicator selection, and Figure 2, which follows, provides an example of how indicators may be evaluated to provide rankings of attribute health at different levels of biological organization. Figure 2 also illustrates the basis for indicator rating. Further details on the development and application of rating criteria are presented in the next section.

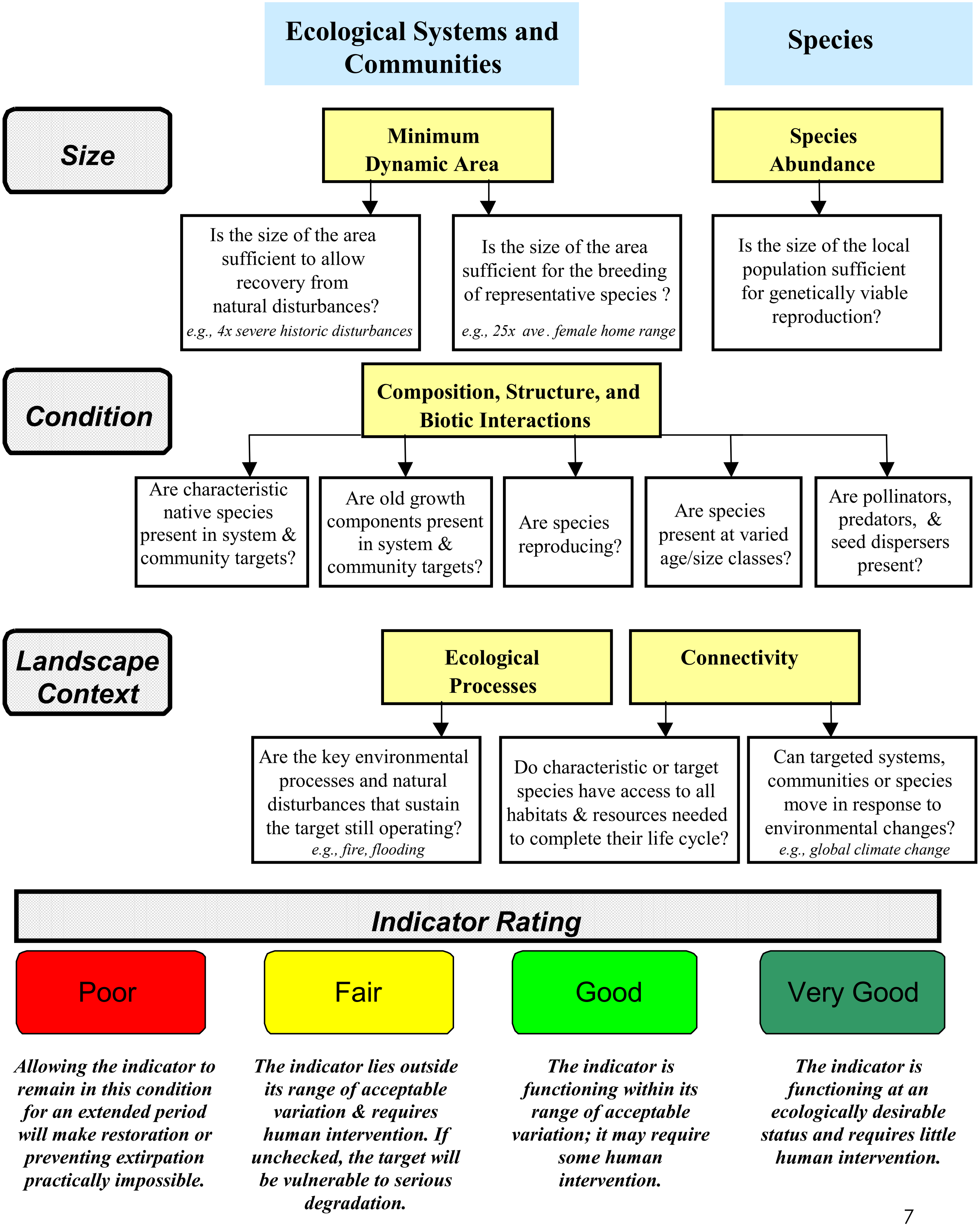
Box 2. Characteristics of Efficient and Effective Integrity Indicators

All indicators should be measurable, precise, consistent, and sensitive. To ensure that indicators are also meaningful and effective for TNC's conservation work, they need to be:

1. *Biologically relevant* (i.e., represent an accurate assessment of biodiversity health)
2. *Socially relevant* (i.e., value is recognized by stakeholders)
3. *Sensitive to anthropogenic stress* and reflective of changes in stress without extreme variability
4. *Anticipatory*, providing early warning (i.e., indicate degradation before serious harm has occurred)
5. *Measurable* (i.e., capable of being operationally defined and measured using a standard procedure with documented performance and low error)
6. *Cost-effective* (i.e., inexpensive to measure, providing the maximum amount of information per unit effort)

Indicators are monitored to track the status of a conservation target, and ultimately to measure the success of our conservation strategies. While the indicators identified may not meet all of these criteria, select those that satisfy the largest possible number (or a complimentary set) and proceed with a strategy for monitoring. Under the premise of Adaptive Management, we can refine the list of indicators as more is learned about the ecological system.

Figure 2. Example Indicators of key ecological attributes[1]. Indicators will vary by attribute and target. Sample types of questions below are illustrative only: they do not represent an exhaustive list.



Is the size of the area sufficient to allow recovery from natural disturbances? *e.g., 4x severe historic disturbances*

Is the size of the area sufficient for the breeding of representative species ? *e.g., 25x ave. female home range*

Is the size of the local population sufficient for genetically viable reproduction?

Are characteristic native species present in system & community targets?

Are old growth components present in system & community targets?

Are species reproducing?

Are species present at varied age/size classes?

Are pollinators, predators, & seed dispersers present?

Are the key environmental processes and natural disturbances that sustain the target still operating? *e.g., fire, flooding*

Do characteristic or target species have access to all habitats & resources needed to complete their life cycle?

Can targeted systems, communities or species move in response to environmental changes? *e.g., global climate change*

Allowing the indicator to remain in this condition for an extended period will make restoration or preventing extirpation practically impossible.

The indicator lies outside its range of acceptable variation & requires human intervention. If unchecked, the target will be vulnerable to serious degradation.

The indicator is functioning within its range of acceptable variation; it may require some human intervention.

The indicator is functioning at an ecologically desirable status and requires little human intervention.

---

[1] Modified from Low, G. 2002. Landscape-scale, Community-based Conservation. TNC.

Assessing Status of Key Attributes: Acceptable Ranges of Variation and Reference Conditions.

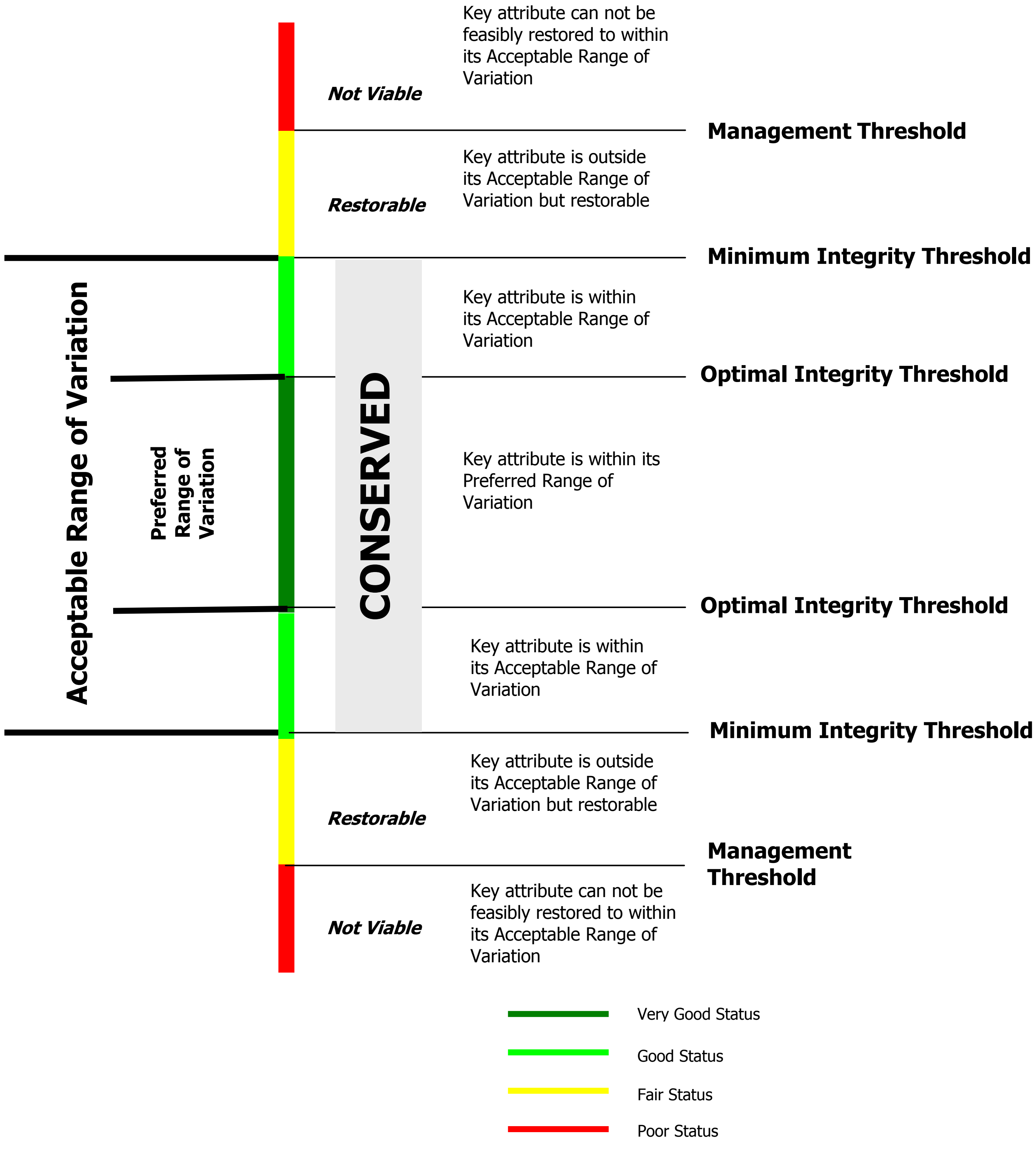
The recommended approach for assessing the ecological integrity of focal biodiversity rests on the widely accepted premise that the composition, structure, and function of all conservation targets - species, communities, and ecological systems - are naturally variable. This dynamism is limited to a particular range of variation that is recognized as natural and consistent with the long-term persistence of each conservation target. More precisely, each key ecological attribute exhibits some "natural range of variation" over space and time. For example, there will be some natural variation in the age and species composition of a forest canopy, the frequency and intensity of fires, or the frequency and magnitude of hurricanes, floods or droughts.

For most biodiversity, what is "natural" is difficult to define, given limited knowledge of many species and systems, and the extent to which human disturbance has either directly or indirectly impacted influenced natural systems around the globe (Hunter 1996). However, through careful scientific reference, reflections on historical data, and comparisons with the best preserved reference examples of a conservation target, at least an outer range of variation for each key ecological attribute can be defined that will maintain the composition, structure and function of the conservation target at acceptable levels over the long-term (Swetman et al. 1999, Stephenson 1999, Moore et al. 1999). For any focal biodiversity to be considered "conserved," all key ecological attributes should remain intact and functioning within their acceptable ranges of variation, as measured by their specific indicators.

As with the identification of key ecological attributes, descriptions of acceptable ranges of variation constitute hypotheses, crucial to carrying conservation work forward while remaining open to refinement over time. It is important to describe the limits of this variation because these limits set the ecological thresholds beyond biodiversity integrity is expected to degrade. For species, such degradation might involve a collapse of population or range; for communities and ecological systems, such degradation might involve change from one community or system type to another.

The most important threshold to consider for each key ecological attribute is its "minimum integrity threshold" (Fig. 3). The minimum integrity threshold for a key ecological attribute is the outer limit of its acceptable range of variation. Once this threshold has been crossed, the overall integrity of the conservation target can not be restored so long as the altered attribute is outside of its range of acceptable variation. The composition, structure, and function of a conservation target may not begin to degrade immediately when one of its key attributes moves outside of its acceptable range of variation. However, this shift can be expected to set in motion chains of events, that will (if unchecked) result in additional alterations to other key attributes and leave them vulnerable to significant disruptions from additional disturbances, that in turn may push the associated attributes still further outside of their acceptable ranges of variation. Defining the minimum integrity threshold for individual key attributes is the mechanism by which ecological science can influence the ecological integrity rating of the focal biodiversity in question. In the Ecological Integrity Assessment framework, the focal biodiversity can only be considered as conserved when all of its key attributes are within their minimum integrity thresholds. Conservation strategies therefore need to focus on keeping or moving the key attribute status to levels that are within acceptable ranges of variation. Such strategies should either abate threats that alter key attributes, or guide ecological management and restoration for key attributes that need intervention to return to acceptable ranges.

Figure 3. Key Attribute Thresholds and Status Assessment. Thresholds for some key attributes can be points (such as a fixed pH beyond which the system loses integrity), for others the threshold may be a range.



The Nature Conservancy's Measures of Success and Assessment of Overall Ecological Integrity

The Nature Conservancy has developed a system of "measures of conservation success" that describes the change in biodiversity health and threat status of all focal biodiversity over time within a conservation planning geography through qualitative ratings (Baumgartner et al., 2000, The Nature Conservancy, 2000). This system rates the status of focal biodiversity's "size", "condition", and "landscape context" as *Very Good*, *Good*, *Fair*, or *Poor*, based on scientific inquiry, in order to convey a snapshot of biodiversity health and conservation progress over time in a clear and compelling manner. The Ecological Integrity Framework seeks to provide increased rigor and consistency to that inquiry by determining the key attributes within the categories of *size*, *condition*, and *landscape context* (Fig. 2), and by rating their status based on the minimum integrity thresholds as stated above.

- *Size* is a measure of area of occurrence of an ecosystem or community, or the population size of a species.
- *Condition* measures biotic interactions and physical or age structure of communities and populations.
- *Landscape Context* refers to the important ecological processes that maintain the focal biodiversity and issues of biological and spatial connectivity.

This categorical framework has proven to be enormously helpful in assisting conservation practitioners think broadly and comprehensively about important elements of the focal biodiversity's ecology that must be managed and conserved, and in allowing practitioners to speak a somewhat common language about these elements.

In the Ecological Integrity Assessment framework, the minimum integrity threshold for a key attribute in The Nature Conservancy's measures of success rating scheme marks the dividing line between a rating of Good (or better) and Fair (or worse) for each key attribute. Therefore, this is the principle threshold that will help define a consistent, scientifically defensible means of determining conserved status for focal biodiversity across a portfolio of conservation areas in an ecoregion.

The Conservancy's measures of conservation success framework requires that biodiversity rated as "Good" or better be further distinguished as "Good" or "Very Good"; and that a target rated as less than "Good" also be distinguished as "Fair" or "Poor". Planning teams often aspire to conserve focal biodiversity so that its key ecological attributes meet a higher standard than merely remaining within their minimum integrity thresholds. Therefore, they should define an additional threshold for each attribute, identifying this higher standard - the "Optimal Integrity Threshold" - for each attribute, which can be defined as occurring when:

- The key attribute is substantially less vulnerable to being pushed outside its minimum integrity threshold by chance events or human caused disturbances, and therefore is perceived with greater confidence to be "secure", and/or
- The key attribute requires little to no human intervention to be maintained within its minimum integrity thresholds, and/or

- The pattern of variation in the key attribute more closely approximates what is known of its "natural range of variation".

Similarly, at the other end of the conservation spectrum, each planning team needs to define the criteria it will use to distinguish between a "Fair" and a "Poor" rating for each key attribute, for its focal biodiversity. In The Nature Conservancy's measures of conservation success, these criteria focus on the severity of alteration of the key attribute away from its minimum integrity threshold, the likely difficulty that a conservation program faces in moving the attribute back toward that minimum integrity threshold, and the urgency it faces for doing so. These criteria will define the "Imminent Loss Threshold" for each attribute, which can be said to crossed when:

- The key attribute is severely altered from its minimum integrity threshold, and/or
- Allowing the key attribute to remain in this condition for another 15-25 years will make restoration of the conservation target or prevention of its extirpation practically impossible, and/or
- It will be highly difficult (complicated, costly, and/or uncertain) to reverse the alteration.

Discussion

Adjusting the Complexity of the Analysis

Conservation planners and practitioners will frequently need to adjust the depth, complexity, and detail of the analysis of ecological integrity using this key attribute approach in order to fit their specific circumstances. These circumstances will vary because of variation in data availability, understanding of the focal biodiversity in question, and socio-economic or resource constraints. In many cases, practitioners will find the need to reduce the number of key attributes and their indicators, at times through nesting and relating of these indicators. Moreover, reliance on qualitative descriptions of the minimum integrity threshold alone, based on comparisons with reference conditions, will be necessary due to lack of quantitative data to describe key attribute thresholds. Further, reliance on expert opinion to rate current status of key attributes (inside or outside its acceptable ranges of variation) may be the minimum that can be provided in order to define conservation strategy needs. In such cases, it is essential that information gaps be enumerated and prioritized to adaptively improve the assessment of ecological integrity.

Tools for the Assessment of Ecological Integrity

The Nature Conservancy has developed an automated Excel-based tool to assist in the assessment of ecological integrity and house the documentation and scientific references for the assignment of ecological integrity status for focal biodiversity. This automated tool guides planners and practitioners measuring conservation impact through a series of questions related to the Ecological Integrity Framework. This tool, although designed for site, or landscape-based conservation projects, can be applied at higher geographic scales (e.g., ecoregions). The program is available at **www. conserveonline.org.**

Table 1 provides an example of one of the spreadsheet tables that was produced with this tool. This example was derived based on analyses of the Consumnes River Preserve, CA. Although we have not yet completed similar analyses for the Middle Sacramento River Project Area, we have begun contacting experts of different scientific disciplines to seek their input on what indicators might be appropriate for inclusion in this process. Table 2 provides a summary of some of the science that we will draw from in completing this project. Details about the focus of some of the studies listed in this table are provided in Golet et al. *in press*. In addition we are working with Kevin Wolf and Associates to post Sacramento River Science on the world wide web. This will greatly facilitate the transfer of information among scientists and conservation practitioners. Furthermore, we expect the web project will significantly advance the cross-fertilization of ideas and the initiation of multi-disciplinary projects. The Sacramento River Monitoring and Research Metadata Project website is at: http://www.sacramentoriverportal.org/demo/index5.htm.

Limitations of the Ecological Integrity Assessment Framework

Applying the EIA framework to real-world conservation projects led to the identification of a number of "stumbling blocks" which are summarized as questions below. Each question is followed by a paragraph that further defines the issue of concern, suggests ways to circumvent potential problems, and acknowledges limitations of the framework.

1) How should planning teams best address the pervasive lack of information?

In many cases, practitioners will find the need to reduce the number of key attributes and their indicators due to any number of project capacity limitations. In addition, reliance on qualitative descriptions of the minimum integrity threshold alone, based on comparisons with reference conditions, will be challenging due to a lack of quantitative data to describe integrity thresholds. Further, reliance on expert opinion to rate current status of key ecological attributes and their acceptable ranges of variation may be the only information available to define conservation strategy needs. In such cases, it is essential that information gaps be enumerated and prioritized to enable future improvement in the assessment process.

2) How can practitioners determining when there is not enough information to carry out an EIA?

Key ecological attributes should be identified by a combination of field-based knowledge, literature search, and an expert opinion workshop. In population viability assessment, efforts are now being made to identify when there is not enough information to carry out a PVA effectively (e.g., Morris et al. 1999). Currently there are no rigid guidelines for when you should not conduct an EIA. However, if planning teams have no published studies to rely on, nor any experts to draw upon for guidance, then an EIA should not be carried out until some scientifically credible information is obtained. In such cases, it is suggested that planning teams contact The Nature Conservancy for support from any of the sites that have field-tested this methodology.

3) How can teams build confidence in, and ultimately be able to falsify key ecological attributes?

Throughout the development of scienctific theory, there have been long periods when conventional wisdom has been wrong (Kuhn 1970). Given that in most cases key ecological attributes will be hypotheses at best, the degree of confidence in such estimates is of primary concern. Confidence in any key ecological attribute would be enhanced if there were published experiments that manipulated a key ecological attribute and a strong system response was detected. In the absence of a well-controlled experiment, there may be a human perturbation that could be interpreted. For example, if the flow regime in a river were hypothesized as a key ecological attribute, then any dramatic alteration of the flow regime should result in the dramatic change in a correlated indicator such as the abundance of a critical species. Tables of such responses should be assembled as part of any EIA as a way of generating a level of confidence about the attributes. As experimental examples are likely to be few, planning teams need to search for ways to engage the scientific community to address the most critical information needs to advance this methodology and its site-specific application.

4) How should planners best define what is "natural?"

Even where the definition of "natural" has been narrowly defined in the "natural flow regime" (e.g., Poff et al. 1997), it is challenging to define unambiguously what the "natural range of variation" is, which is central to the identification of integrity thresholds. This is particularly relevant as time marches on, and human alterations become not only more pervasive and ubiquitous (e.g., global climate change), but alter the actual disturbance dynamics and variability that form the core of this methodology. In the best cases, pre-existing data will be available to describe the status of the conservation target *prior* to significant human alteration. In such cases, we propose the use of the RVA approach (Richter et al. 1997) and use the 25th and 75th percentiles unless there is more compelling information to suggest otherwise. We propose looking back over a time frame of relevance to conservation – and focus on the past 100 years. In this way, it is hoped that value judgements will be kept to a minimum about what defines "natural" in each case.

Conclusions

The guidance provided in this report on how to apply the ecological integrity assessment (EIA) methodology applies to all three levels of biological organization – species, communities, and ecosystems – at all biogeographic scales. The use of key ecological attributes and their indicators, combined with a rigorous evaluation of critical thresholds within their ranges of variation provide an explicit basis for rating the integrity of conservation targets. The benefits of this approach to the conservation practitioner include:

- simplifying and strengthening the identification of monitoring indicators to detect progress toward meeting conservation goals.
- providing a framework for identifying stresses to a conservation target by defining stress as any alteration to one of its key ecological attributes.
- identifying critical research needs directed at the most essential components to advance the conservation of priority natural resources.
- improving the efficacy and efficiency of expending scarce conservation resources to improve conservation practices.
- supporting a framework to advance our understanding of complex ecological systems necessary for improving the impact of conservation efforts.

Table 1. Example of a partial viability assessment table. This was developed for the *Vernal Pool Grassland Target* for the Consumnes River Preserve. Similar tables are in the process of being developed for the Sacramento River.

Category	**Key Ecological Attribute**	**Indicators**	**Indicator Ratings** **Categorical** Current state: shaded; *Italics* = Long-term Management Objective				**Basis for Rating**	**Short-term Management Objective**	**Current Status** [Date]	**Basis for Current Status Rating**	**Short-term Mgmt Obj Met?**
			Poor	***Fair***	***Good***	***Very Good***					
Vernal Pool Grassland Target: Landscape Context	Fire Area-Intensity Regime	Buffer around vernal pool complex that can be fire managed	< 0.25 mile buffer	0.25 - 0.49 mile buffer	0.5 – 0.99 mile buffer	*> 1 mile buffer over >80% of the perimeter of vernal pool properties*	Marty (TNC) 2001	Maintain a buffer of ≥ 1 mile around vernal pool complex on large vernal pool tracts	1 mi buffer intact around Howard and Schneider Ranches (2001)	Analysis of remote sensing data	Only for 2 of the large tracts, so no
Landscape Context	Fire Area-Intensity Regime	Fire return interval and area burned	Fire return interval < 1 year or > 10 years for > 10% of the vernal pool grassland.	Fire return interval between 7-10 years for > 10% of the vernal pool grassland.	Fire return interval between 5-7 years for > 50% of the vernal pool grassland.	*Fire return interval between 3-5 years for > 80% of the vernal pool grassland.*	Marty (in prep) 2001; R. Wills pers comm.; Pollak & Kan 1998; Menke1992	Maintain a prescribed fire return interval of 3-5 years for over 80% of the vernal pool grasslands on the Preserve.	> 10 year fire return interval for > 10% of the Preserve's vernal pool grasslands	Historical fire data	no
Landscape Context	Connectivity of vernal pool complexes	Distribution of land permanently protected	< 10% connectivity	10-49% connectivity	50-74% connectivity Note: 15-25,000 ac would be protected with this connectivity to be rated good.	*75% or highter connectivity*	CRP Planning Team 2000; *This Land. Context is linked to the area protected under Size, below.*	Establish 75% connectivity of protected vernal pool habitat by 2005	> 50% connectivity (DE. 2001)	Actual land or easement purchases	no
Condition	Native species diversity	Native species cover	Relative native species cover (RNSC) in vernal pools < 80%	RNSC in vernal pools 80-84%	RNSC in vernal pools 85-90%	*RNSC in vernal pools >90%*	Monitoring data – Marty (2001)	Maintain relative native species cover >90% in vernal pools	Howard Ranch mean-90%, se=1.7%; Valensin Ranch –Mean=84%, se=3% (2001)	Monitoring data (Marty 2001)	no
Condition	Native species diversity	native species richness	Richness on pool edge <5 species/quadrat (35 cm x 70 cm)	Richness on pool edge 6-8 species/quadrat	*Richness on pool edge 9-10 species/quadrat*	Richness on pool edge >10 species/quadrat	Monitoring data – Marty (2001)	Maintain average native species richness on the pool edge >10 species/quadrat	Howard Ranch mean-10.4, se=0.32; Valensin Ranch –Mean=9.4, se=0.34 (2001)	Monitoring data (Marty 2001)	yes
Condition	Pollination	overall		?			See regeneration of species but populations are heavily fragmented	Need baseline data to determine quantitative measures for this indicator – hold expert meeting	No information on what or how to measure. Identify experts and hold meeting: 2003.		?
Size	Size of vernal pool complexes	Acres of land permanently protected through conservation easement or other	< 10,000 acres protected,	10,000 to 15,000 ac protected	15,000 to 25,000 ac protected Note: This acreage would be protected with 50-74% connectivity to be rated good.	*30,000 ac protected*	CRP Planning Team 2000; *This Size is linked to the connectivity under Land. Context, above.*	Protect 30,000 ac of vernal pool habitat with 75% in large, contiguous parcels by 2005	17,000 ac protected (Dec. 2001)	Actual land or easement purchases	no

Table 2. Partial list of studies of ecosystem dynamics on the Middle Sacramento River.

Project Title	Participants	Affiliation	Funding Source	Site Locations	Available Documents
Birds and Bird Predators	Geoff Geupel Stacy Small Joanne Gilchrist	PRBO PRBO-PhD student PRBO	Various	SRNWR	Proposals Reports Manuscripts
State transition modeling, Classification of Vegetation Communities, Red Bluff to Colusa Reach, Sacramento River, CA	Mehrey Vaghti, Steven Greco Alex Fremier Jay Lee Truil	UCDavis-MS student UCDavis UCDavis-MS student UCDavis-MS student	DWR	Emphasis on river bends at Pine Creek and below Woodson Bridge; approx. 100 vegetation survey locations.	Proposals
Recruitment of herbaceous species	Karen Holl Elizabeth Crone	UCSC U of Montana		Dave Jukkola has shape file	Proposals
Terrestrial Inverts	John Hunt	CSUC-MS student	CALFED 97-NO3	Rio Vista, plus WCB lands south, Pine creek & Phalen Island	Proposals
Ground water, soil develop- ment and nutrient cycling	David Brown David Wood Carey Wilder	CSUC CSUC CSUC-MS student	CALFED 97-NO3	74387 (Brown, Wilder) 74388 (Wood, Hunt)	Proposals Reports
Salmonids, Salmonid Prey	Michael Marchetti Mike Limm	CSUC CSUC-MS student	CALFED Beehive Bend	N/A	Proposal
Stratigraphy, geomorphology & cottonwoods	Karin Hoover Walter Van Gronigen	CSUC CSU-MS student	CALFED Beehive Bend	Shaw Bar, RM 172 & RM 183, all on west side of river	Proposal
Evolution of backwater habitats	Matt Kondolf Herve Piegay Gundrun Bornette Ingrid Morken	UC Berkeley Nat'l Centr for Scientific Research, Lyon, FR; U Caude Bernard, Lyon, FR; UCB-MS student	TNC, DWR		Proposal Final Report
Isotopic Studies, Aquatic Food Web Dynamics, Bats	Mary Power Bruce Orr Frank Ligon Bill Rainey Dixie Pierson Sapna Khandwala	UC Berkeley Stillwater Sciences Stillwater Sciences UC Berkeley ? Stillwater Sciences	CALFED 97-NO3	La Barranca, Kopta Slough, Shaw Bar	Proposal
Turtles	Dawn Wilson	CSUC	Various	Sam Slough, Murphy Slough, North of Pine Creek	Proposal Report

Table 2 (continued). Partial list of studies of ecosystem dynamics on the Middle Sacramento River.

Project Title	Participants	Affiliation	Funding Source	Site Locations	Available Documents
Meander Migration Modeling	Eric Larsen	UC Davis	CALFED 97-NO2	RM 201-185	Proposal
Grassland Restoration	Jim Coleman Hall Cushman	Sonoma State U Sonoma State U	USFWS & Anderson Foundation	Llano Seco & Vermet Field	Proposal
Baseline Assessments of Future Restoration Sites	Jean Hubble David Wood John Hunt Matt Quinn Ryan Luster	CSUC CSUC CSUC-MS Student CSUC-MS Student TNC	TNC	Haleakala, Deadman's Reach, Capay, RX Ranch, Sunset Ranch	Proposal
Grassland Restoration, Competition & Establishment	Matt Quinn Tom Griggs Dan Efseaff	CSUC CSUC Sac River Partners		Llano Seco T4	Proposal
Bird Food Identified Through Fecal Examination (feasibility study)	Scott Chamberlain Karen Holl Elizabeth Crone Aaron Gabbe Charles McClair	CSUC UCSC U of Montana UCSC UCSC	Research experience for undergraduate grant from NSF (to Holl, Wood)	Sul Norte, Phalen Island	Proposal
Black Walnut Genetics	Paul Kirk Christina Schierenbeck	CSUC CSUC	CSUC Bio Dept		Proposal
Soil Stratigraphy Mapping with Conductivity	Eileen Ernenwein Donald Sullivan	U Denver-PhD student U Denver			Proposal
Elderberry Associated Insects	Marcel Holyoak Teresa Talley	UCDavis UCDavis-post doc		Various riparian woodland sites with elderberry in the vicinity of Chico. Considered both natural and restored sites	Proposals
Pollinators	Neal Williams	Princeton U	TNC Smith Fellow		Proposal
How Management Scenarios Affect Rates of Floodplain Sedimentation, includes dating sediments with Lead-210	Rolf ________ Michael Singer Tom Dunne	U Washington UC Berkeley UC Santa Barbara	CALFED	Plan to collect 500+ sediment cores from sites on Sac floodplain from Keswick to Freeport	Manuscripts
Species richness of medium-sized carnivores & riparian patch size	Earl Jeffrey Souza	CSUC	TNC	10 sites between Red Bluff & Colusa	Masters thesis

Table 2 (continued). Partial list of studies of ecosystem dynamics on the Middle Sacramento River.

Project Title	**Participants**	**Affiliation**	**Funding Source**	**Site Locations**	**Available Documents**
Species-Area Relations of Breeding Birds on the Middle Sacramento River, CA	L. Breck McAlexander	CSUC			Report to TNC (1994) and Master's Thesis
Nest Site Selection & Nesting Success of the Western Wood Pewee (*Contopus sordidulus*) in the Sacramento Valley, CA	Carrie Bemis	CSUC-grad student		Sacramento River NWR, Flynn Unit & Woodson Bridge State Park	Masters thesis Spring 1996
Fisheries Monitoring	Charles Brown David Grant	CDF&G CDF&G	CDF&G	Mouth of Stoney Creek at Phelen Island Unit	Brief Reports
Natural Process Restoration	Daryl Peterson Dave Wood	TNC CSUC	TNC	Sul Norte	Masters Thesis 2002
Survival & Growth of Valley Oaks at Restoration Sites	Tom Griggs Greg Golet	CSUC TNC	Some from TNC		Manuscript
Status of Yellow-Billed Cuckoo	Dave Gilmer Jim Snowden Steve Laymon Murrelet Halterman Gary Falxa	USGS-Dixon ? Kern River Research Ctr Kern River Research Ctr USFWS-Sacramento	USGS, USFWS	River wide	Report
Vegetation Dynamics at Restoration Sites & Remnant Riparian Sites	Dave Wood Greg Golet Ryan Luster Brianna Borders Joe Silveira	CSUC TNC TNC CSUC-MS Student USFWS	CALFED-Beehive Bend, TNC Fresh Water Initiative	River wide	Proposals
LaBarranca Gravel Pit Restoration Feasibility Study	Dan Efseaff Tom Griggs	CSUC Sac River Partners	AFRP grant to Sac River Partners	La Barranca	
Bank Swallow Surveys	Ron Schlorff Joe Silveira	CDF&G USFWS	CDF&G & USFWS		
Indicators of Hydrologic Alteration (IHA) Studies	Shawn Pike Stacy Cepello	DWR DWR			
Cottonwood Recruitment Pilot Study	Mike Roberts Stacy Cepello	TNC DWR	CALFED97-N02		Final Report
Current Status Report on Cottonwood Recruitment	Karin Hoover Sara Nash	CSUC CSUC	CALFED - Beehive Bend	RM 165-206 (30 sites)	Draft Report
Channel Cut-Off Investigation	Eric Larsen	UCDavis			
Sediment Mobility Study	Koll Buer	DWR	DWR		
Water Temperature Regime Study	Cindy lowney				Dissertation
Refuge Wildlife Surveys	Joe Silveira	USFWS	USFWS		Reports Manuscripts

Table 2 (continued). Partial list of studies of ecosystem dynamics on the Middle Sacramento River.

Project Title	Participants	Affiliation	Funding Source	Site Locations	Available Documents
Soil Vegetation Associations at Llano Seco, Chico, CA	Joe Silveira	USFWS, SSRP, NRCS	USFWS, SRP, NRCS	Llano Seco Unit (USFWS), Llano Seco Ranch	Soils (1998) Vege
Competitive Effects of Inter-cropping Alfalfa with Valley Oak & Blue Elderberry Seedlings	Jean Hubbell	CSUC		Kopta & Llano Seco	MA Thesis
Influence of Riparian Vegetation on Water Temperature in the Sacramento River, CA	Cynthia L. Lowney ?	DWR			Report to USFWS
Sacramento River, Glenn, Butte & Tehama Counties: A Study of Vegetation, Deposition & Erosion and a Management Proposal	Thomas J. Kakremer	CSUC			Master's Thesis
Monitoring Riparian Landscape Change & Modeling Habitat Dynamics of the Yellow-Billed Cuckoo on the Sacramento River, CA	Steven E. Greco	UCDavis			Dissertation
Riparian Vegetation Distribution Along the Middle Sacramento River in Relation to Flood Frequency	Stacy Cepello	CSUC			Master's Thesis
Leaf Litter Decomposition Rate	Brianna Borders David Wood James Pushnik Dave Brown	CSUC		Princeton Ferry, River Vista, Phelan Island, Pine Creek, Shaw Bar, Flynn	Master's Thesis
Sediment Transport	Koll Buer				
Bank Erosion and Meandering Studies	Koll Buer				
Human Effects on Geomorphic Processes	Koll Buer				
Effects of Dams & Diversion on the River	Koll Buer				
Spatial patterns of woody plant regeneration in two California Central Valley floodplain forests	William Jones	U of Montana-MS student		Kopta Slough Pine Creek	Master's Thesis
Hyporheic Zone (ground water, river water interactions)	Stacy Cepello Thomas Boullion				
Bank swallow population and ecology studies	Ron Schlorff B Garrison Kerry Moffatt Elizabeth Crone	DFG DFG U of Calgary U of Montana			

Literature Cited

Barbour, M.T., J. Gerritsen, B.D. Snyder, and J.B. Stribling. 1999. Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, Second Edition. EPA 841-B-99-002. U.S. Environmental Protection Agency; Office of Water; Washington, D.C.

Crouse, D., L. Crowder, and H. Caswell. 1987. A stage-based population model for loggerhead sea turtles and implications for conservation. Ecology 68:1412-1423.

Dale, V. H. and S. C. Beyeler. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1: 1-3.

Doak, D.F., P. Kareiva, and B. Klepetka. 1994. Modeling population viability for the desert tortoise in the Western Mojave Desert. Ecological Applications 4:446-460.

Feinsinger, P. 2001. Designing field studies for biodiversity conservation. Island Press, Washington, D.C.

Ginzburg, L.R., S. Ferson, and H.R. Akcakaya. 1990. Reconstructibility of density dependence and the conservative asessment of extinction risks. Conservation Biology 4: 63-70.

Groves, C., L. Valutis, D. Vosick, B. Neely, K. Wheaton, J. Touval, and B. Runnels. 2000. Designing a Geography of Hope: A Practitioner's Handbook for Ecoregional Conservation Planning, 2nd Edition. The Nature Conservancy, Arlington, VA.

Holling, C. S., editor. 1978. Adaptive Environmental Assessment and Management. John Wiley & Sons., New York.

Hunter, M. L. 1996. Benchmarks for managing ecosystems: Are human activities natural? Conservation Biology 10: 695-697.

Jackson, L. J., A. S. Trebitz, and K. L. Cottingham. 2000. An introduction to the practice of ecological modeling. Bioscience.

Kuhn, T. S. 1970. The structure of Scientific Revolutions. Second Edition. University of Chicago Press. Chicago, IL.

Maddox, D., K. Poiani, and R. Unnasch. 2001. Evaluating management success: using ecological models to ask the right monitoring questions. Pp. 563-584 in Ecological Stewardship, Vol. 3., W. T. Sexton, A. J. Malk, R. C. Szaro, and N. C. Johnson, eds. Elsevier Science, Oxford.

Noss, R.F., and A. Y. Cooperrider 1994. Saving Nature's Legacy: Protecting and restoring biodiversity. Island Press, Washington, D.C.

Moore, M. M., W. Wallace Covington, and P. Z. Fulé. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9: 1266-1277.

Morris, W., D. Doak, M. Groom, P. Kareiva, J. Fieberg, L. Gerber, P. Murphy, and D. Thomson. 1999. A practical handbook for population viability analysis. The Nature Conservancy, Arlington, VA.

Olsen, D.M., E. Dinerstein, G. V. N. Powell, and E.D. Widramanayake. 2002. Conservation biology for the biodiversity crisis. Conservation Biology 16: 1-3.

Poff, N. L, J. D. Allan, M.B. Bain, J. R. Karr, K. L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The Natural Flow Regime: A paradigm for river conservation and restoration. BioScience 47(11):769-784.

Richter, B.D, J.V. Baumgartner, J. Powell, and D.P. Braun. 1996. A method for assessing hydrologic alteration within ecosystems. Conservation Biology 10(4) 1163-1174.

Richter, B.D., J. V. Baumgartner, R. Wigington, and D.P. Braun. 1997. How much water does a river need? Freshwater Biology 37:231-249.

Salafsky, N. and R. Margoluis. 1999. Threat reduction assessment: a practical and cost-effective approach to evaluating conservation and development projects. Conservation Biology 13: 830-841.

Salafsky, N., R. Margoluis, and K. Redford. 2001. Adaptive management: A tool for conservation practitioners. Biodiversity Support Program, Washington, D.C.

Scott, M.S., T.H. Tear, and L.S. Mills. 1995. Socioeconomics and the recovery of endangered species: Biological assessment in a political world. Conservation Biology 9(1): 214-216.

Shaffer, M. 1987. Minimum viable populations: coping with uncertainty. Pages 69-86 in M.E. Soule, editor. Viable populations for conservation. Cambridge University Press, New York.

Stephenson, N. L. 1999. Reference conditions for giant sequoia forest restoration: structure, process, and precision. Ecological Applications 9: 1252-1265.

Swetman, T. W., C. D. Allen, and J. L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9: 1189-1206.

The Nature Conservancy, 2000. The Five-S framework for site conservation: A practitioner’s handbook for site conservation planning and measuring success. The Nature Conservancy, Arlington, VA.

United States Army, Corps of Engineers, Cottonwood Creek Hydrology Report, 1997

Walters C. J. 1986. Adaptive Management of Renewable Resources. Macmillan, New York.

Water Resources Commission (2001). State of the Rivers Report, Letaba and Luvuvhu River Systems, 2001. WRC Report No. TT 165/01, Water Resources Commission, Pretoria, South Africa.

Wilson, E.O. 1988. Biodiversity. National Academy Press. Washington, D.C.

Wootton, J. T., and D. A. Bell. 1992. A metapopulation model for the Peregrine Falcon in California: viability and management strategies. Ecological Applications 2:307-321.

World Resources Institute, 2000. People and ecosystems: The fraying web of life. World Resources Institute, Washington, D.C.