69 An approach to identifying "vital signs" of ecosystem health

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This paper presents an approach for scoping workshops to identify indicators of ecosystem health. This approach is based on systems concepts, and results in indicators that are clearly tied to a stressor-based model of the ecosystem. The approach is particularly designed to produce results that will be feasible for smaller parks, with relatively small staffs, to undertake.

This paper focuses on human-generated stressors. Discussion of the difference between these stressors and natural disturbances is beyond the scope of this paper and will be covered in a forthcoming paper, as will the concept of ecosystem health.

In addition to indicators of ecosystem health, a comprehensive program should also monitor those relevant to:

- Statutory requirements;
- "Primary" park resources for which the park was explicitly established;
- Resources that contribute to the visitor experience;
- Resources of particular interest to the public; and
- Issues of national or international concern.

Parameters in each of these five categories can be identified through means other than a scoping workshop. This paper focuses on identifying indicators of ecosystem health, in order to make the best use of the experts who attend a scoping workshop.

Systems concepts

Several characteristics of systems are relevant to identifying indicators of the health of an ecological system.

Hierarchy of scale. In the interconnections among the diverse components that compose a "middle-number system" such as an ecosystem, there is a hierarchy of scale. For example, a wetland system consists of components such as water, algae, amphibians, plants, and insects. The wetland system, in turn, is one component of a higher-scale system—a watershed (Figure 69.1).

Keystones. Interconnections within a system vary in their strength. "Dominant" species have a great effect on the structure and function of the ecosystem simply because they are so abundant. Other, less-abundant "keystone" species have an influence on the system that is far out of proportion to their abundance.

The keystone concept also applies at other levels of ecosystem scale (Southerland 1999). In some ecosystems there are keystone habitats. Desert springs are certainly a keystone habitat. In their absence, the desert ecosystem would be quite different. Estuaries have also been suggested as being keystone habitats.

Redundancy. The species in a guild may seem redundant in their function. However, each species is slightly different in its capabilities. These differences enable the function to continue in the ecosystem in spite of changing conditions. Rather than being redundant, the multiple species bring resilience to the system.

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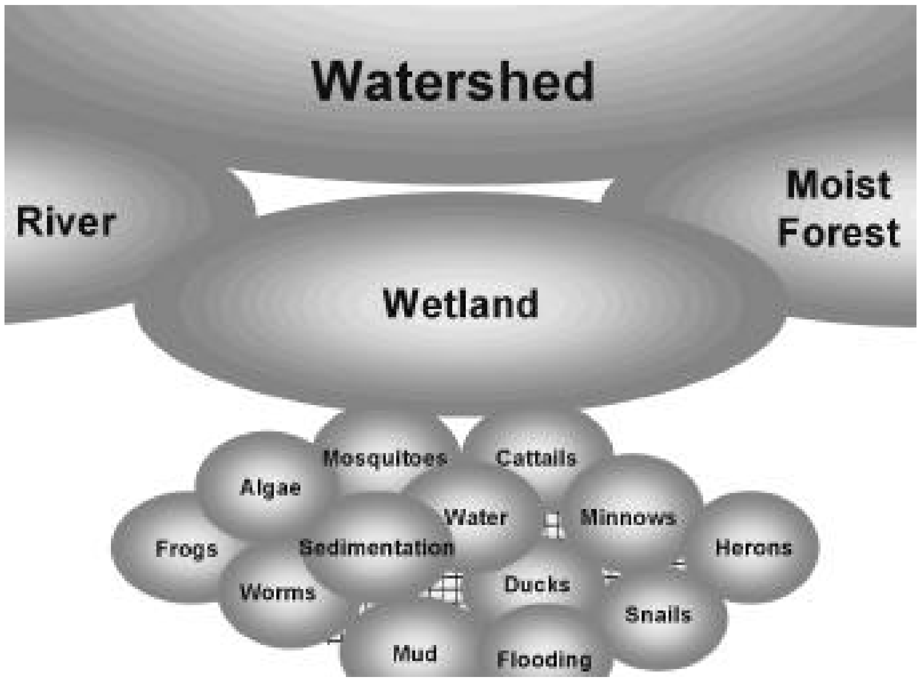

Figure 69.1. Illustrating the hierarchy of scale in an ecosystem. A wetland ecosystem consists of many diverse, interconnected components. At the next higher level of scale, the wetland along with a river system and adjacent forest system interconnect to form a watershed.

Some past monitoring programs have focused on species considered "representative" of a guild. Yet research has documented compensatory changes among species in a guild: as one species declines, others increase. In view of this, a monitoring program which assumes that one species is representative of others must rigorously test this assumption.

Organization and phase shifts. Systems are self-organizing through feedback loops that tend to damp change. These feedback loops can persist through a moderate degree of stress. As stress is increased, such as through loss of species or changing climatic conditions, there comes a threshold at which the feedback loops are no longer effective, and the system undergoes profound change, becoming a qualitatively different system.

Such "rollover" constitutes an essentially irreversible shift of the system to a new "stable state." Examples can be seen when acidic input exceeds a lake's buffering capacity, or when decades of fire suppression lead to a new system that is self-perpetuating.

The scoping workshop

Our approach to the identification of vital signs involves a three-day scoping workshop, involving at least a dozen experts from within and outside of the National Park Service (NPS). Participants represent a diverse range of multidisciplinary expertise. There are facilitated break-out sessions, involving at least two break-out groups. Each group intentionally has a mix of disciplines to help ensure an ecosystem approach that considers the interrelationships among ecosystem components and processes. Individual input is sought in ranking the resultant suggested indicators. Throughout the workshop, care is taken to avoid violating the Federal Advisory Committee Act.

The primary question addressed through the workshop is: How can we use knowledge of how stressor effects flow through the ecosystem to document whether the condition of the ecosystem is declining? The intent is to work on building a stressor-based conceptual model of the ecosystem. We recognize that models are developed with a specific use in mind, and a foodweb-based model may be very different from a stressor-based model. Our workshops begin to formulate a stressor-based model not as the *basis* for the discussions, but *through* the discussions.

Agents of change. The first step in the workshop process is for the park to identify tentative "agents of change" (Roman and Barrett 1999). While we have in the past referred to "visitors," "adjacent development," and "pollution," for example, as stressors, each of these in fact involves numerous stressors. Visitors, adjacent development, and pollution are, instead, agents of change that impose ecosystem-changing stressors.

Stressors. The next step of the workshop is to use the inter-disciplinary breakout groups to list specific stressors associated with each agent of change. For example, some stressors associated with the agent of change "visitors" are:

- Human presence;
- Litter;
- Sewage;
- Physical disturbance—trampling, erosion;
- Removal of things;
- Introduction of exotic species; and
- Water use.

Ecosystem effects. In the next step, the breakout groups brainstorm the ecosystem changes elicited by each stressor. A report of the U.S. Environmental Protection Agency (Southerland 1999) identified ten important ways in which human activities tend to affect ecosystems. Rapport (1992) and Costanza et al. (1992) suggested that this pattern of changes can be referred to as the "ecosystem distress syndrome."

1. *Habitats critical to ecological processes.* Loss of keystone habitats, such as desert springs, estuaries, and other "centers of organization" of the ecosystem.
2. *Pattern and connectivity of habitat patches.* Increased homogeneity across the landscape, with significantly larger patch sizes, loss of rare habitats, loss of connectivity among habitat patches, and no source of replenishment when local extinctions occur.
3. *Natural disturbance regime.* Alteration of natural disturbance regimes, such as fire, flood, and insect infestations; reduced ability to withstand stressors; higher levels of destruction from natural stressors, even when within their normal range of variability.
4. *Structural complexity.* Loss or reduction of components that create structural diversity, such as coarse woody debris in streams and downed trees; reduced structural complexity in riparian areas; breakage of the fragile edges on lava flows; and reduced complexity of micro-site structure.
5. *Hydrologic patterns.* Altered water chemistry, wider swings in water temperature, reduced infiltration, increased surface flow, wider swings in flow and increased "flashiness."
6. *Nutrient cycles.* Disruption of feedback loops that conserve and recycle nutrients, increased leaching of nutrients from the system, and alteration in the levels and normal patterns of variation of nutrients.

7. *Purification services.* Disruption of mechanisms by which the ecosystem breaks down wastes and detoxifies contaminants; addition of waste materials, toxics, acid, or other contaminants in amounts or at rates that exceed the capacity of the ecosystem to process them.
8. *Biotic interactions.* Reduced complexity of interactions among species; loss of specialized species, with generalist species making up a greater proportion of the biota; loss of narrow mutualist relationships; loss of species with vulnerable life histories, such as migratory species; replacement of perennial plants by annuals; increased homogeneity of life histories among the remaining species.
9. *Population dynamics.* Disruption of mechanisms that tend to damp down fluctuations in populations; increased "overpopulations," irruptions, and crashes.
10. *Genetic diversity.* Loss of certain genotypes; reduced genetic variation; increase in genetically based deformities and reproductive dysfunction.

Workshop participants are asked to keep these patterns in mind as they brainstorm the ecosystem effects elicited by each stressor.

In the example above, one stressor associated with the agent of change "visitors" was water use. In this particular instance, "water use" meant the withdrawal of water from an arid-land stream. Ecosystem changes resulting from this stressor may include:

- Reduced overall water flow;
- Loss of stream in dry years;
- Loss of fish;
- Altered aquatic invertebrate community;
- Altered riparian plant structure;
- Altered stream temperature patterns;
- Altered riparian bird community;
- Altered riparian invertebrate community;
- Altered soil characteristics; and
- Altered soil water-holding capacity

These include not only direct effects, but also indirect ones—secondary, tertiary, and beyond—elicited by the stressor.

"Cascading effects." Workshop participants are then asked to examine linkages among these stressor effects and identify the flows of stressor effects through the ecosystem. This represents the beginning of a stressor-based conceptual model of the ecosystem. Figure 69.2 illustrates how the effects of the stressor "water withdrawal from an arid-land stream" cascade through the ecosystem.

Monitoring questions. Monitoring questions are specific questions, derived from the conceptual ecosystem model, concerning specific ecosystem effects and stressors. These monitoring questions will be the basis for establishing measurable indicators. Examples of monitoring questions from the example above are:

- How much of the stream's water is being withdrawn, relative to its flow?
- Is the stream becoming ephemeral?
- Are vulnerable amphibians declining?
- Is the structure of riparian plant communities changing?
- Is the stream water becoming warmer?
- Are specialized riparian bird species declining?

These monitoring questions clearly reflect the ten key types of effects identified by Southerland (1999). They illustrate how this approach leads to a monitoring program that will address the ecological system much more fully than would a program that focuses solely on the populations of various plant and animal species.

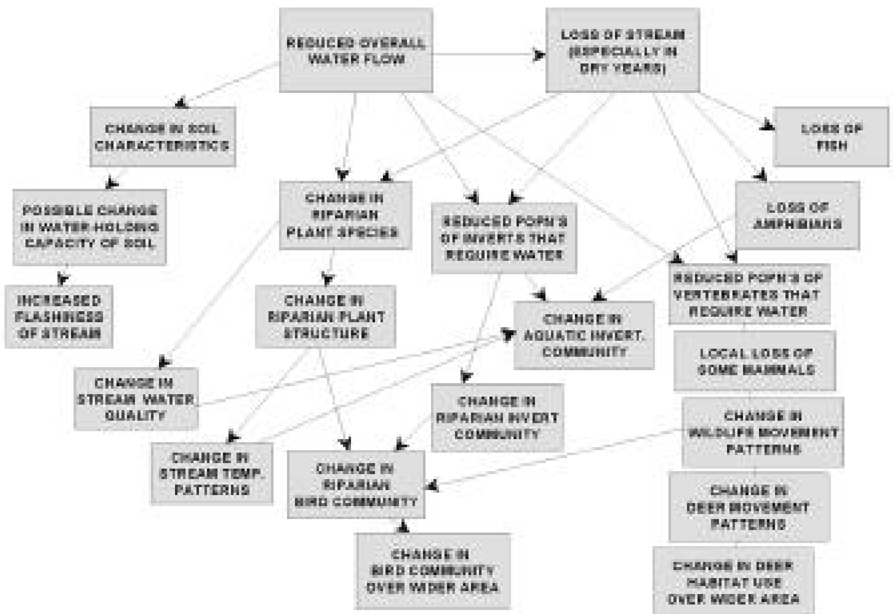

Figure 69.2. Illustration of the cascading flow of ecosystem effects elicited by the stressor "water withdrawal from an arid-land stream."

Propose indicators. In considering possible indicators, it is important to recognize three categories of indicators:

- *Stressor indicators* are measures of the stressor itself, such as the amount of water pollution or air pollution emitted by a source. A drawback of measuring the stressor itself is that there is no indication of the ecosystem consequences.
- *Exposure indicators* are measures of the amount of stressor to which the ecosystem is exposed, such as the concentration of water pollutants in a stream
- *Response indicators* are measures of changes that occur in the ecosystem, such as genetically based deformities in amphibians. A drawback of response indicators is that they do not provide clear evidence of the cause (O'Laughlin et al. 1994).

The type of indicator selected should be a conscious decision, giving consideration to the strengths and weaknesses of each type in a given situation.

Some indicators are *diagnostic,* specific to a given stressor. They can be used in monitoring focused on a known or suspected stressor. Other indicators are *non-diagnostic* (similar to blood pressure in humans), reflecting the "ecosystem distress syndrome" and changes that tend to be elicited by many types of stressors in all types of ecosystems (Council of Great Lakes Research Managers 1991).

Some indicators may be better at providing early warning, while others are retrospective, providing evidence of ecosystem change after the change has occurred. The Council of Great Lakes Research Managers (1991) suggested that the best early-warning indicators tend to be non-diagnostic. Diagnostic indicators, on the other hand, tend to be more retrospective (Figure 69.3).

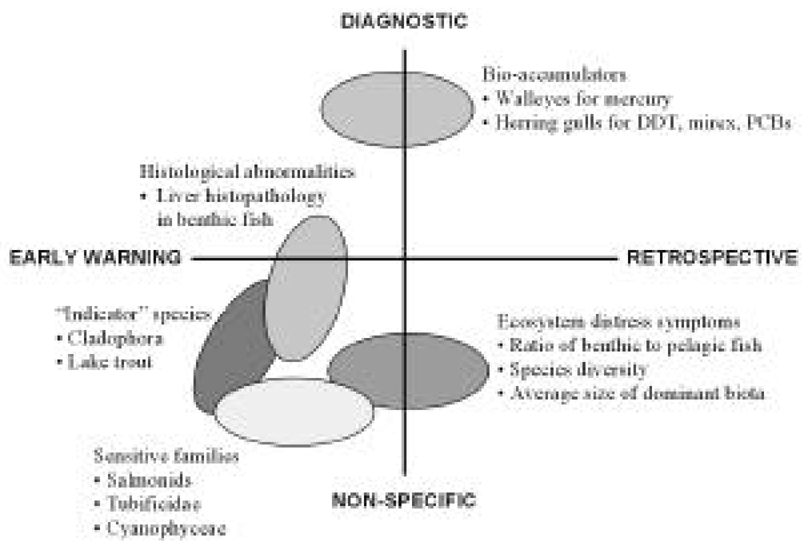

Figure 69.3. Relationship between the early warning vs. retrospective quality of indicators, and whether they are diagnostic or non-diagnostic. From Council of Great Lakes Research Managers 1991.

As Olympic National Park has noted, where there is a known stressor of concern, indicator selection is based on the predicted response of the ecosystem to that stressor. For stressors that are not yet recognized, but which may occur now or in the future, indicator selection focuses on early-warning non-diagnostic indicators of ecosystem health. Stressor- or issue-specific monitoring may be shorter-term, while early-warning monitoring is likely to be long term. A comprehensive monitoring program should include a combination of relatively short-term stressor-specific monitoring and long-term ecosystem-health monitoring to provide an early warning of changes.

In the workshop, each participant is asked to individually select a stressor and associated ecosystem response, develop a monitoring question, and propose a measurable indicator. It is suggested that each participant do this five times, proposing five indicators.

In the example we've been following, with the stressor "withdrawal of water from an arid-land stream," proposed indicators might include the following:

- Duration and timing of low flow;
- Volume diverted vs. stream volume;
- Areal extent of riparian habitat;
- Riparian canopy coverage at the overstory, middle-story, and understory levels;
- Composition and relative abundance of nesting riparian bird species;
- Trout population size;
- Frog population size;
- Composition and relative abundance of aquatic macroinvertebrate species;

- Population index of aquatic mollusks; and
- Deer population within one mile of the stream.

Ranking indicators. The next step of the process is for the participants to individually rank the indicators. Ranking criteria may include:

- Ecological significance of the ecosystem change being measured;
- Management significance of the stressor;
- Urgency, or vulnerability to essentially irreversible change; and
- One or more criteria reflecting the quality of the indicator.

Each of these criteria is rated on a scale of 1 to 5, with 5 representing the greatest significance, urgency, or quality. The intent is not to produce a total score for each indicator, but to provide feedback to the park on the significance, urgency, and quality of each indicator.

Scores are compiled and the results presented to the park for its use in selecting candidate indicators. The park should also review the stressors and ecosystem effects to ensure that significant ones were not omitted simply because no one happened to propose an indicator for them.

Many authors have presented their thoughts on what makes for a high-quality indicator (for example, Hinds 1984; Council of Great Lakes Research Managers 1991; Cairns et al. 1993; Trame and Tazik 1995; Lewis et al. 1996; McRae et al. 1996; Herlihy et al. 1997; Pankhurst 1997; Summers et al. 1997; Woodward et al. 1999). Characteristics of an ideal indicator include its being:

- Based on the conceptual model;
- Clearly connected to the function it reflects;
- At an appropriate scale;
- Anticipatory;
- Timely;
- Broadly applicable to many stressors (for early-warning indicators);
- Sensitive to the stressor (for diagnostic indicators);
- Measurable;
- Constant during the period of measurement;
- Easy to measure;
- Non-destructive to measure;
- Robust;
- Unique; and
- Socially appealing.

In addition, the ideal indicator will have a high "signal-to-noise" ratio, known variability and other statistical properties, and the capacity to be communicated to managers and the public.

Suggest methodologies. In the final step of the workshop, each participant is asked to provide information on possible methodologies, literature citations, names of authoritative experts, and other information relevant to each of the indicators.

Conclusion

As a result of this workshop, the park has a list of potential indicators of ecosystem health, each with a clear connection to a stressor-based conceptual model of the ecosystem. The park has feedback on the significance and quality of each indicator, which can be used in narrowing the list to a relatively small number of the most important indicators. While even this amount of monitoring, or the technical expertise required, may be beyond the capability of a park with a small staff, this gives the park some direction in seeking technical assistance to further develop its monitoring program.

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