National Park Service
U.S. Department of the Interior

Northeast Region
Philadelphia, Pennsylvania

Structure and Functioning of Large River Ecosystems in the Eastern Rivers and Mountains Network: Conceptual Models and Vital Signs Monitoring

Natural Resources Report NPS/NER/NRR—2006/010

ON THE COVER
View of the New River in West Virginia, a large river within the Eastern Rivers and Mountains Network.
Photograph courtesy of The National Park Service.

Structure and Functioning of Large River Ecosystems in the Eastern Rivers and Mountains Network: Conceptual Models and Vital Signs Monitoring

Natural Resources Report NPS/NER/NRR—2006/010

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Executive Summary

The purpose of this report is to present a brief scientific description about large river ecosystems, their essential ecosystem characteristics (i.e., communities, habitats, species, and processes), how they interact with each other, and how anthropogenic stressors affect them at different spatial scales.

The description is accomplished by using a diagrammatic conceptual modeling approach beginning with Karr's (Karr 1991,1999; Karr and Chu 1999) general ecological model of rivers, and then focusing on stressors that are either foreign to the system or that occur outside of what we interpret as their natural range of variation. The model is intended to be a brief synthesis of current scientific understanding, field observations, and professional judgments regarding large river ecosystems. This report is not, however, intended to present regional details about the riverine park units or to rank the stressors by their level of importance.

A short list of vital signs was then developed for consideration into a riverine monitoring program. The list was designed to include at least one indicator each of the geological, hydrological, chemical, and biological condition of the system; one indicator each of the most likely natural and human influences on the system; and one early warning indicator of potential health hazard to park visitors.

The final section contains this list of candidate vital signs and the rational behind their inclusion.

Introduction

Some Key Ecological Concepts about Large Rivers – A Conceptual Model

Most of the large rivers of the Eastern Rivers and Mountains Network (ERMN), like their counterparts worldwide, have been altered by a variety of human activities (Welcomme 1985; Dynesius and Nilsson 1994; Galat and Frazier 1996; Purvis 2002; Mahan 2004). Humans have altered the physical templates of rivers, the hydraulic dynamics of their channels and tributary networks, and the land-use characteristics of their basins. On such disturbed systems, management requires the restoration of altered system features to desired levels of quality (National Research Council [NRC] 1992) and the conservation of river features that still exhibit desirable conditions.

Our scientific knowledge of large river ecosystems has expanded greatly over the last three decades (Johnson et al. 1995; Lorenz et al. 1997; Ward 1998; Tockner and Stanford 2002); however, there is a great need to confirm many of our hypotheses with data from the rivers. The following concepts about river ecosystem structures, functions, and controlling factors are generally well-accepted today by many river ecologists. Future monitoring within the riverine park units will probably support many of these hypotheses, but we should expect to find that some of them will be incomplete. Future revisits to this conceptual model will thus provide an opportunity for work on the riverine park units to contribute to a better understanding of the class of ecosystems called large rivers.

The ecological condition of a large river depends on drivers and stressors that exist at multiple spatial scales (Frissell et al. 1986; Lubinski 1993; Naiman 1998; Ward et al. 2001; Wiens 2002). Drivers that operate at larger spatial scales tend to exert control over longer temporal scales and cycles (Poff and Ward 1990; Naiman 1998). Geology, climate, and basin land cover have often been considered as primary drivers of streams and river ecosystems (Bhowmik et al. 1984; Resh et al. 1988). Under undisturbed conditions, river processes and dynamics vary over time, responding to seasonal, annual, and long-term changes in the three drivers. Water and sediment discharge regimes within the basin stream network provide the major mechanisms for the drivers to affect changes in the river dynamics. Within a basin, as rivers increase in size in the downstream direction, predictable gradients occur in the forces that shape the river, control the substrate, and provide organic material (Webster and Patten 1979; Vannote et al. 1980).

Large rivers are located at lower elevations than smaller streams within the same basin. They often have shallower elevation gradients than their tributaries and therefore trap more sediment and have longer water-retention times. These conditions, with the exception of local areas where the channel is constricted, generally result in lower water velocities and substrates dominated by finer particles. Under natural conditions, the discharge of a river increases with distance downstream. The predictability of the flow regime of a large river is typically greater than the predictability of its smaller, flashier tributaries (Johnson et al. 1995).

Under natural conditions, the primary sources of biological metabolic energy in a large river, detritus, fine particulate organic material, and attached bacteria, are usually allochthanous, that is, carried downstream by tributaries. The River Continuum Concept (Vannote et al. 1980) holds

that local photosynthesis in large rivers is limited by turbid water. However, the presence of dams, floodplains with large backwaters, or large amounts of woody debris in a given large river reach (e.g., large pools) can reset metabolic energy processes to conditions more like those that occur in moderate size streams (Ward and Stanford 1983; Junk et al. 1989; Thorp and DeLong 1994; Bayley 1995). Under these conditions, in-stream (autochthanous) energy production through photosynthesis and increased invertebrate production increases.

In large rivers with substantial floodplains, annual flood pulses have been identified as perhaps the most important hydrologic feature that governs year-to-year changes in ecosystem productivity and possibly diversity (Junk et al. 1989; Ward 1989).

Large rivers frequently exhibit distinctive reach or microhabitat characteristics that are attractive to individual or groups of species (Stalnaker et al. 1989; Montgomery and Buffington 1998; Ward 1998). Reach distinctions frequently are reflected in different vegetation patterns, community types, and habitat assemblages (Lubinski 1993). Microhabitat attractions are often most clearly observed during specific life-history stages, seasons, or discharge ranges. An especially important characteristic of large rivers is that conditions in their microhabitats change widely with river discharge (Reash 1999). Population changes in response to year-to-year variations in discharge are considered to be an important contributor to riverine biodiversity (Galat et al. 1998; Knutson and Klaas 1998).

The flora and fauna of large rivers are adapted to and respond in large part to the conditions discussed above. It is also important to keep in mind, however, that large-scale distribution patterns of many species, terrestrial and aquatic, in the region still reflect zoo-geographic patterns established by glacial processes that transformed land masses, lakes, and rivers thousands of years ago.

Large rivers, within the context of either their tributary networks or even broader spatial scales, function as landscape corridors (Lubinski and Theiling 1999). In this role, they provide ecological services such as removing wastes and transporting nutrients, sediments, and water itself to systems downstream. The landscape corridor function of large rivers is of special value to migratory birds and fishes, in some cases extending beyond the basin itself (as in the case of migratory bird and diadromous fish species).

General Conceptual Model

A variety of large river models have been developed that can be considered conceptual in nature (Amoros et al. 1987; Ward 1989; Karr 1991; Lubinski 1993; Bayley 1995). Although these models share many similarities, each contains unique elements, a result, in part, of the need to use the models for different purposes.

Here, we begin with and modify Karr's (1991, 1999; Karr and Chu 1999) basic conceptual model of stream and river ecosystems (Figure 1). The model focuses on biological and ecological endpoints and five factors (Flow Regime, Water Quality, Energy Source, Biological Interactions, and Physical Habitat) that influence or modify the components of ecological integrity. Ecological integrity applies to the condition of places/systems at one end of a continuum of human influence: those that support a biota that is the product of evolutionary and

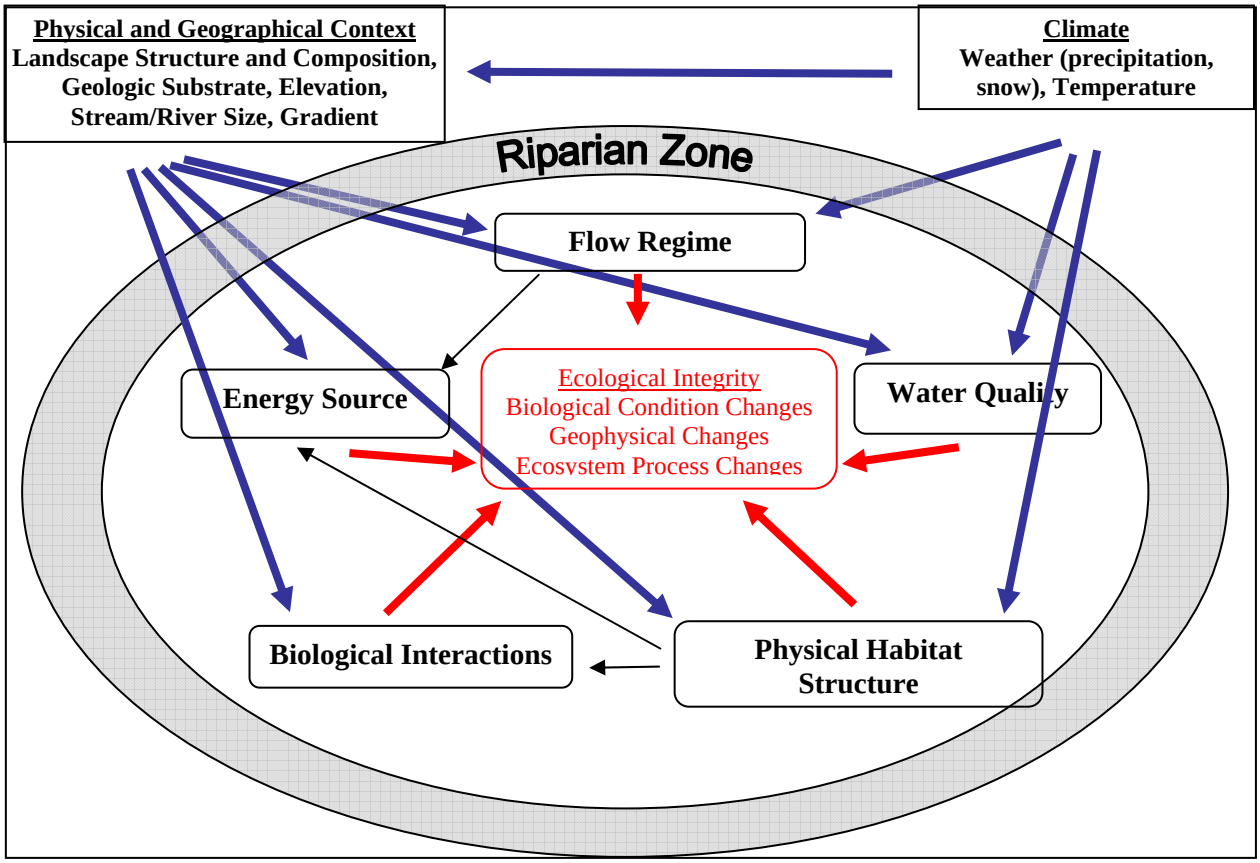

Figure 1. Basic conceptual model of a stream/river ecosystem and its elements (modified from Karr 1991, 1999; Karr and Chu 1999).

biogeographic processes with minimal influence from modern human society, *sensu* Karr 1999. These five factors provide a critical conceptual and analytical framework to judge the interactions of human activities and ecological change.

Adding Anthropogenic Model Elements

We then show (Figure 2) how human activities (e.g., agriculture, recreation, urbanization, etc.) operate through a series of stressors (e.g., altered delivery of water, altered water quality, increased nutrients, etc.) to alter biogeochemical processes which influence one or more of the five factors, thereby, altering one or more elements of ecological integrity (Figure 2). These factors constitute a hierarchy of cause-effect relationships.

Most large rivers have been altered by a relatively large number of anthropogenic drivers. Thus, it should not be surprising that Figure 2 contains ten anthropogenic agents of change operating though nine stressors. The connections shown between the drivers, stressors, and attributes in Figure 2 are, essentially, hypotheses, yet are intended to convey a high probability of effect in any large river. However, the relative importance of the connections may differ substantially

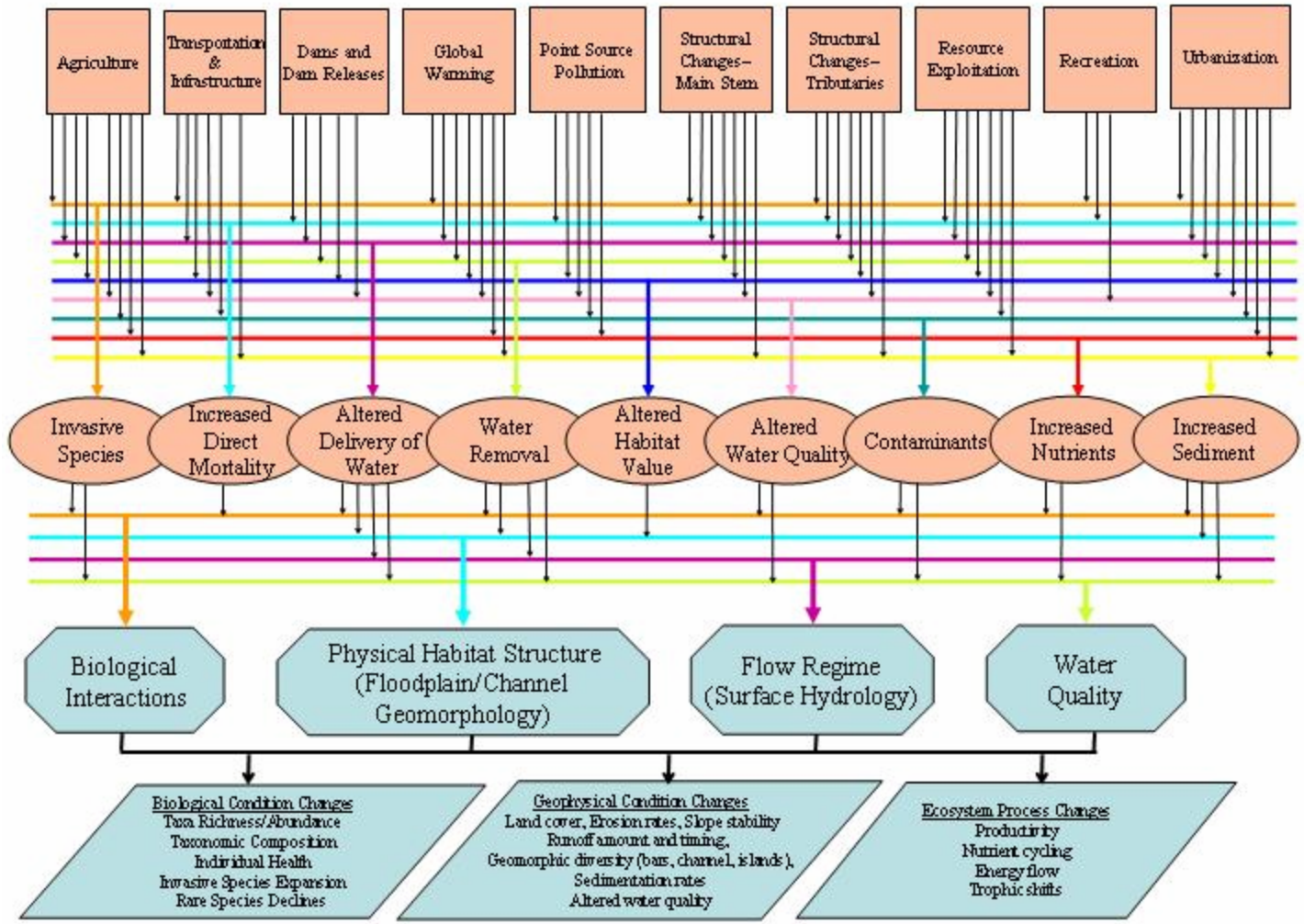

Figure 2. Tributary watershed anthropogenic agents of change (rectangles), stressors (ovals), Karr's (Karr 1991, 1999; Karr and Chu 1999) four ecosystem factors (octagons), and elements of ecological integrity. Connections (probable causal linkages) are represented by colored lines and thin vertical arrows.

from one reach to the next, or from one time or flow period to another. Valuable discussions of such changes in connection strength are only possible when extensive local information about the river reach of interest is available.

Discussion of Model Elements

The structure and function of these ecosystems, including the influence of human activities and stressors, is considered under four general headings (Figure 1) corresponding to Karr's "five factors" (*Biological Interactions, Physical Habitat Structure, Flow Regime, Water Quality, and Energy Source)*. Given the emphasis on trend detection, and the need to narrow the number of large river components to a set that could function in an operational monitoring program, we dropped one factor, energy source, from further consideration. This factor has not been quantified extensively in large rivers, and the lack of strong data sets or routine methods for measuring this component makes it difficult to consider it as a viable trend detector.

Biological Interactions

In large rivers, native species include resident species that remain in place throughout the year and migratory species. The management of migratory species requires special attention to spatial scale, as the migration corridor function provided by the river can be vulnerable at any point along the corridor, not just at monitoring locations.

The pulsing nature of a large floodplain river, which typically floods from April through June, results in complex patterns of species habitat use patterns (Ward et al. 2002). Large river biodiversity, though difficult to quantify because of the sampling scales involved, is frequently considered high relative to smaller streams. A few selected studies have begun to provide the data to support that perception (Knutson and Klass 1998; Shiel et al. 1998; Schiemer 1999). The tendency for larger rivers to support more fish species than smaller rivers within a stream network is well known (Welcomme 1985).

Overall riverine biodiversity has been suggested as a unifying theme for river ecology (Ward and Tockner 2001), and taxa-specific indicators have been developed to assess ecological integrity (Wehr and Descy 1998; Karr 1999; Schiemer 2000).

Physical Habitat Structure

This factor refers to the physical template, aquatic and terrestrial, over which river water flows. Under natural conditions, the physical structure of any given river reach is determined by its gradient, water, and sediment regimes (Montgomery and Buffington 1998). Floodplain/channel geomorphology contributes to what we generally think of as habitat, but it is a system attribute, whereas habitat is defined by the species or guild of interest. Not all large rivers have floodplains, but when floodplains are present they play an important role in sediment transport and deposition, carbon and nutrient recycling, the distribution of species, and the availability of food (Ward 1989).

Hydrology/Flow Regime

Because of its ecological importance, water flow in large rivers has sometimes been referred to as a “master” variable (Poff et al. 1997; Richter et al. 1997; Galat and Lipkin 2000). Together with floodplain/channel geomorphology, it is a major determinant of where species can be found in the large river system. Water flow includes multiple variables, including discharge, velocity, and water-level elevation.

Water Quality

By water quality, we include temperature and the chemical compounds, gases, and other constituents that would naturally be present in the water column of a large river. For this model, we also considered some foreign materials in river waters as aspects of water quality rather than as strictly contaminants (i.e., stressors). Key water quality variables that control ecological processes or species behavior in large rivers include temperature, dissolved oxygen, suspended and bed sediment loads, dissolved and suspended carbon, and nutrients. Water temperatures play a great role in controlling the reproductive timing and success of river fishes. Low dissolved oxygen concentrations can make certain areas of the river unsuitable for use by most aquatic organisms and may occasionally cause kills. Sediment not only plays a role in fluvial dynamics and the succession of riverine plant communities, but also controls (with plankton) the turbidity of river water, which can limit the amount of photosynthetically active radiation available to submerged plants.

Candidate Vital Signs for Large River Ecosystems

Approach

A list of potential purposes or components of a riverine monitoring program was developed (Table 1), and three individuals at the U.S. Geological Survey (USGS) Northern Appalachian Research Lab, Wellsboro, PA (William Lellis, Robert Ross, Martin DiLauro) reviewed and rated each vital sign (provided to them by the NPS Eastern Rivers and Mountain Network [ERMN] staff) based on ecological significance towards understanding riverine systems and the potential value to a monitoring program. The list was also sent to four individuals for additional review and comment (Bob Hilderbrand, U. Maryland; Karen Riva Murray, USGS; Paul Angermeier, Virginia Tech; Peggy Johnson, Penn State).

A literature review was conducted and a conceptual approach to selected vital signs developed based on concepts presented by Karr 1999 (Figure 3) and above (Figures 1 and 2). The model and conceptual approach is based on the concept that both natural factors and human activities affect the physical, hydrological, and chemical characteristics of the river. In combination, these abiotic factors shape the structure and distribution of biological communities, which can themselves be analyzed to infer the environmental conditions in which they live. Undesirable changes in biological communities would lead to policy or actions intended to alter human activities that negatively impact the physical, hydrological, or chemical environment. This feedback loop was considered to be an important element of a monitoring program based on the assumption that the NPS would want to use monitoring information to protect and preserve park resources, rather than simply document change over time.

A short list of vital signs was then developed for consideration into a riverine monitoring program. The list was designed to include at least one indicator each of the geological, hydrological, chemical, and biological condition of the system; one indicator each of the most likely natural and human influences on the system; and one early warning indicator of potential

Table 1. Potential purposes or components of a large river monitoring program.

Number	Purpose or Component Description
1	Document current condition
2	Monitor change over time
3	Evaluate human impact
4	Determine sources of impacts
5	Monitor specific known stressors
6	Monitor predicted future stressors
7	Monitor biological condition
8	Monitor keystone species
9	Monitor target species of interest
10	Monitor threats to park visitors

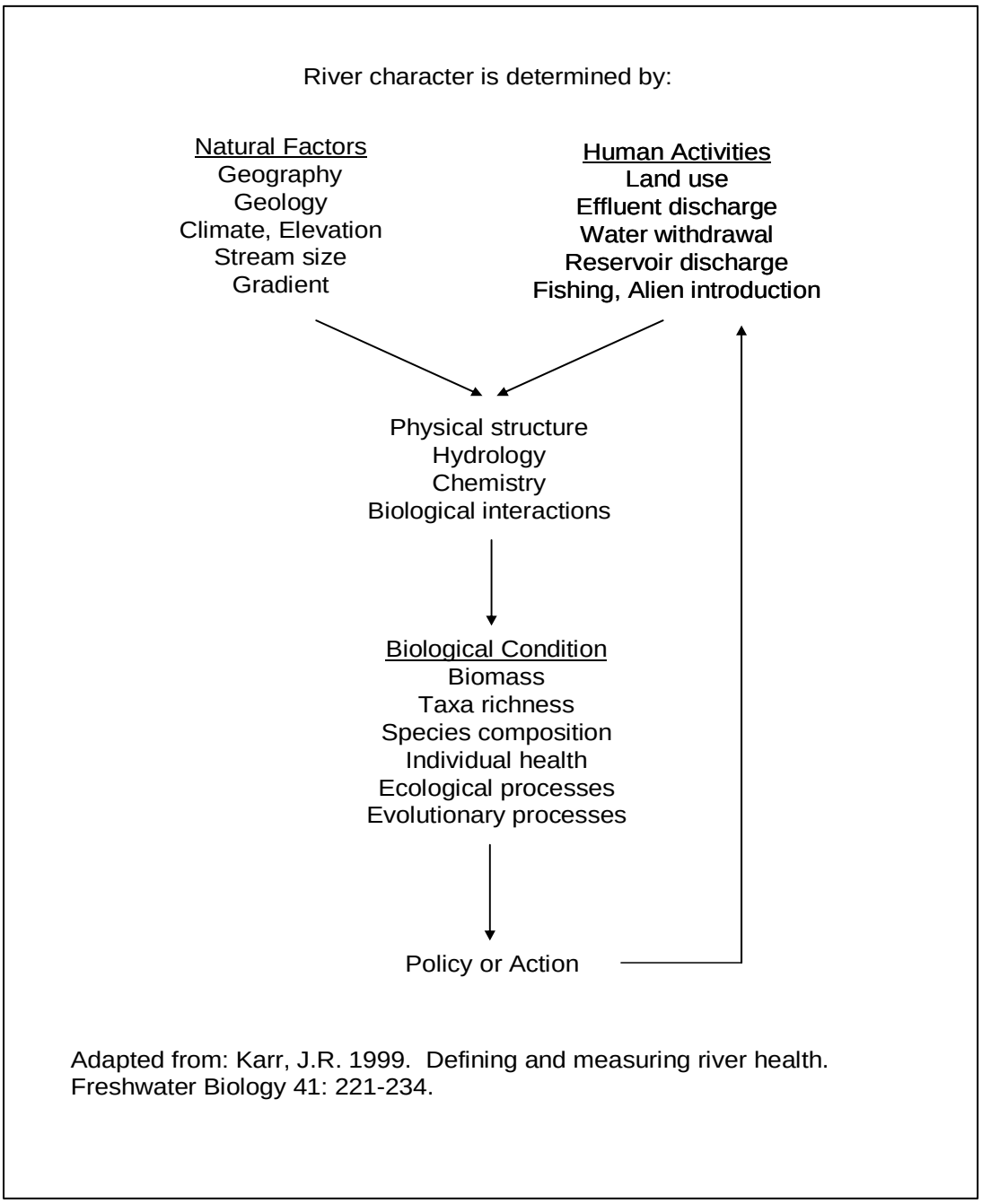

Figure 3. Conceptual approach to selecting vital signs for large river ecosystems.

health hazard to park visitors. Indicators were only considered in the context of the river systems within ERMN parks. The short list was arbitrarily limited to ten vital signs based on the assumption that rivers would only be a portion of the total monitoring program, and finances and manpower would be constrained. Relevance to all riverine parks was considered, and the riparian zone was considered part of the river system. Vital signs were not prioritized within this short list, outside of inclusion or non-inclusion.

Candidate Vital Signs

The following section contains a list of candidate vital signs and the rational behind their inclusion.

River channel geomorphology: The most important geological determinant of river and riparian character that can be altered by natural and human influences. Of particular importance is sediment transport and deposition. Intended to be monitored at long intervals or after major events.

Surface water hydrology: The most important hydrological determinant of river and riparian character that can be altered by natural and human activities. Of particular importance to the ERMN due to water withdrawal, containment, and release from impoundments on mainstem and tributaries. Long-term data sets and ongoing monitoring programs by USGS.

Water quality core parameters: The most important chemical determinant of riverine character, largely altered by human activity. Core parameters include dissolved oxygen, pH, specific conductance, and water temperature.

Water quality expanded parameters: Indicators of specific human activities such as agriculture, development, and industry. Of particular importance is nutrient loading and fecal coliforms.

Aquatic macroinvertebrates: Most robust indicator of cumulative physical and chemical impacts on biological communities. Monitoring techniques are standardized and well-developed. Many matrices available. Ongoing federal and state programs.

Fish communities: Higher level indicator of biotic integrity. Also indicator of park natural resource usage and general detection of invasive species. Can be tied to contaminants and aquatic animal disease monitoring programs.

Riparian plant communities: Most important indicator of riparian zone biological integrity. Detection of riverine biodiversity. Particularly important in detection and monitoring of riverine invasive species.

Bioaccumulation of toxins: A practical means of monitoring toxic compounds and metals that exist in low concentrations or are pulsed through the ecosystem. Indicator of potential health risk to park visitors.

Weather and climate: The most important natural influence on riverine conditions. Long-term data sets available and ongoing federal and state monitoring programs. Data needed to separate natural variation from human-induced change.

Land cover and land use change: The most important human influence on riverine conditions in ERMN parks outside of water management through impoundments. Changes in land use and development outside park boundaries are likely to have major impacts on park resources over the next century. Parks will need this information to interact with local community planning boards.

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Appendix. Detailed summary narratives of select vital signs.

Level 1 – Geology and Soils

Level 2 – Geomorphology

Level 3 – River Channel Characteristics/Geomorphology

Brief Description: "Stream channel characteristics" (SCC) refers to the physical component of stream/riverine habitat and includes information on stream/river size, sinuosity, bed roughness, channel slope, bank condition, water depths, water velocities, substratum, and the amount and type of organic matter and instream vegetation. Usually, measurements of physical habitat are collected in conjunction with hydrology (flow), water chemistry, and riparian vegetation sampling. Individual SCC variables are typically summarized using traditional statistical measures of magnitude and variance such as means and standard deviations, as well as with more complex, integrated, measures such as habitat complexity and substrate stability.

Significance/Justification: Measures of habitat quality are essential components of any long-term stream monitoring program. Along with water quality, the physical characteristics of stream channels are the main proximate determinants of biotic integrity in streams. Individual species or life stages of a single species vary with respect to physical habitat requirements and preferences, and SCC variables summarized at various spatial scales represent a multidimensional representation of individual habitat patches important to component species. Over long stream reaches it is the diversity and stability of available habitat patches as determined by SCC, as well as the spatial and temporal relationships among them, that shape biological communities in streams (Townsend 1989; Poole 2002). Moreover, SCC indirectly affect biological communities through their influence on energy flow. Specifically, SCC variables, such as bed roughness, pool-riffle ratios, and the amount of coarse woody debris within the channel, are primary determinants of carbon and nutrient flow through and retention within lotic systems (Brookshire and Dwire 2003).

In undisturbed watersheds, SCC are determined by interactions between climate, basin size, geology, and terrain (Gordon et al. 1992). However, both natural and human-induced disturbances can have profound effects on SCC and, consequently, biological integrity. For example, increases in the amount of impervious surfaces associated with urbanization within a watershed have been shown to cause higher stormflows which lead to bank erosion (i.e., changes in stream size), increased sedimentation (reduced substrate size and increased substrate embeddedness, especially in riffle areas), shallower and less complex pool habitats, and, ultimately, reduced biotic integrity (Richards et al. 1996; Snyder et al. 2003). Consequently, understanding status and trends in biological integrity of stream ecosystems requires basic information on SCC.

Proposed Metrics: Important SCC metrics include mean channel width, substratum size distributions (especially in riffles), substrate embeddedness, amount and size distribution of large woody debris, proportion of stream channel area with submerged and emergent vegetation, pool-riffle ratios, number and size of dispersal barriers (beaver dams, waterfalls, man-made dams and

dikes), measures of bank stability, and variation in depth and flow patterns. In addition, integrated measures such as instream habitat diversity, fish cover, and substrate stability are also recommended.

Prospective Method(s) and Frequency of Measurement: Two types of methods are typically used to assess stream habitat: quantitative assessments that involve detailed measurements of stream channel and bank characteristics (e.g., Rosgen 1994); and visual-based rapid assessments that involve relative rankings of important stream habitat features. Quantitative assessments have the advantage of providing accurate and unbiased data that can be collected by trained field technicians; however, these measurements are time consuming and require a significant amount of field equipment. In contrast, with visual-based rapid approaches a very large amount of information can be acquired in a relatively small amount of time with little equipment; however, these visual rankings are more sensitive to investigator bias and, consequently, a significant amount of training and testing is required to minimize subjectivity and ensure comparability. It is usually recommended that a single biologist conduct all visual-based assessments.

If possible, a combination of the two approaches should be used with quantitative methods applied less frequently (perhaps once every five years) and rapid assessments used more often (e.g., annually). The EPA has developed and tested a visual-based habitat assessment approach which is described in Barbour et al. (1999). Specific rapid protocols have been developed for both low- and high-gradient stream systems. Quantitative habitat assessment protocols are described by Meador et al. (1993), Rosgen (1994), and Kaufmann and Robinson (1997).

Limitations of Data and Monitoring: As previously mentioned, substantial training of field crews is required to minimize subjectivity of the qualitative rankings used in the rapid habitat assessment approach. Moreover, rankings are often affected by current weather conditions. In contrast, the quantitative approach is more expensive and time consuming and requires a significant amount of equipment.

Key References:

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, DC.

Brookshire, E. N. J., and K. A. Dwire. 2003. Controls on patterns of coarse organic particle retention in headwater streams. Journal of the North American Benthological Society 22:17–34.

Gordon, N. D., T. A. McMahon, and B. L. Finlayson. 1992. Stream Hydrology: an Introduction for Ecologists. John Wiley and Sons. NY. 526 pp.

Kaughman, P. R., and E. G. Robinson. 1997. Physical habitat assessment. Pp. 6-1 to 6-38 in D. J. Klemm and J. M. Lazorchak (editors). Environmental Monitoring and Assessment Program. 1997 Pilot Field Operations Manual for Streams. EPA/620/R-94/004. Environmental Monitoring Systems Laboratory, Office of Research and Development, U.S. Environmental Protection Agency. Cincinnati, OH.

Meador, M. R., C. R. Hupp, T. F. Cuffney, and M .E. Gurtz. 1993. Methods for characterizing stream habitat as part of the national water-quality assessment program. U.S. Geological Survey Open-File Report. Raleigh, NC. USGS/OFR 93-408.

Poole, G. C. 2002. Fluvial landscape ecology: addressing uniqueness within the river discontinuum. Freshwater Biology 47:641–660.

Richards, C., L. B. Johnson, and G. E. Host. 1996. Landscape-scale influences on stream habitats and biota. Canadian Journal of Fisheries and Aquatic Sciences 53:295–311.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169–199.

Snyder, C. D., J. A. Young, R. Villella, and D. P. Lemarie. 2003. Influences of upland and riparian land use patterns on stream biotic integrity. Landscape Ecology 18:647–664.

Townsend C. R. 1989. The patch dynamics concept of stream community ecology. Journal of the North American Benthological Society 8:36–50.

Related Environmental Issues and Linked Vital Signs: SCC are primary determinants of stream biotic assemblages and, consequently, should be considered along with any stream faunal groups selected for monitoring. In turn, SCC are themselves effected by weather, geology, and riparian and upland landcover characteristics.

Overall Assessment: SCC should be considered a high priority vital sign because they are both drivers of ecological integrity in streams, and sensitive to many of the sources of environmental degradation noted for ERMN.

Level 1 – Water

Level 2 – Hydrology

Level 3 – Surface Water Hydrology

Brief Description: Riverine watersheds consist of a complex of streams, riparian zones, and wetlands that are supported by various combinations of precipitation, surface water, and groundwater. The physiographic origins, flow patterns, hydrodynamics, and water quality attributes determine the mosaic of aquatic habitats in these systems. Understanding hydrologic reference conditions is critical for diagnosing hydrologic stressors.

Significance/Justification: Understanding and measuring the hydrology of riverine watersheds is central to many other ecological aspects of assessing the condition of these systems (Forman 1995; Thorp et al. *in press*). As the primary driver of these systems (Mitsch and Gosselink 2000), and as a link between climate and weather indicators, hydrology should be considered a core vital sign. From an energy perspective, the ecological integrity of stream and riverine communities is determined mostly by factors that affect retention, transport, and the quality of organic matter from headwater areas upstream, and by factors that influence instream primary production within mid-reach areas. The effects of non-point source pollutants associated with agriculture and urban land use in upstream or adjacent landscapes (both of which are significant concerns in ERMN) have been shown to affect energy pathways in these reaches. Herbicides and increased sediment inputs have been shown to reduce overall instream primary production with subsequent changes in macroinvertebrate diversity and production (Guasch et al. 1998). Acidification of stream habitats has also been shown to alter primary production in streams.

Proposed Metrics: Hydrologic measurements are relatively standardized. The placement of equipment to acquire those data, however, must be strategically considered. Each park unit should determine its needs for hydrologic data, potential partnering opportunities, and costs in order to design an appropriate hydrologic monitoring system. Given the importance of hydrology to these systems, it is important to capture as much of these data as possible. In some cases, particularly for floodplains and wetlands, observed hydrologic indicators can be used as surrogates to quantitative measures.

Prospective Method(s) and Frequency of Measurement: Hydrologic data typically originates from gaging stations, from which flow rates, frequency of flooding, and other hydrologic measurements can be derived. Gaging stations, however, can only be installed on limited reaches due to the relatively high expense of the equipment. Modeling and other types of simulations can be used to extend empirical measurements across other streams. The network of gaging stations can be extended through partnering efforts with other agencies and organizations. Groundwater measurements for streams and wetlands typically are taken from wells and piezometers placed at various depths into soil and geologic strata. Automated or hand measurements can be taken. The sampling regime for hydrologic measurements should be coordinated with water quality data collection to allow the computation of loadings and to increase efficiency.

Limitations of Data and Monitoring: Due to the expense of installing and maintaining an extensive hydrologic monitoring system, careful consideration should be given to the locations of sampling stations and types of surface water and groundwater data.

Key References:

Forman, R. T. 1995. Land mosaics: the ecology of landscapes and regions. Cambridge University Press. 632 pp.

Guasch, H., N. Ivorra, V. Lehmann, M. Paulsson, M. Real, and S. Sabater. 1998. Community composition and sensitivity of periphyton to atrazine in waters: the role of environmental factors. Journal of Applied Phycology 10:203–213.

Mitsch, W. J., and J. G. Gosselink. 2000. Wetlands. 3rd edition. John Wiley & Sons. New York, NY.

Thorp, J. H., M. C. Thoms, and M. D. Delong. (in press.) A model of biocomplexity in river networks across space and time.

Related Environmental Issues and Linked Vital Signs: Hydrologic measurements are key to diagnosing stressors in riverine watersheds. Whether obtained as quantitative measurements or as qualitative observations, documenting deviations from reference hydrologic conditions is important.

Overall Assessment: Hydrologic data are neither easy nor inexpensive to obtain, but their utility to monitoring the condition of aquatic ecosystems is critical.

Level 1 – Water

Level 2 – Water Quality

Level 3 – Water Quality – Core Parameters

Brief Description: Four key parameters will be measured: pH, dissolved oxygen concentration, specific conductance, and temperature. Serious fluctuations in any of these four core parameters can cause major disruptions in the biota living within the aquatic system, which can lead to major fish, macroinvertebrate, and plant mortalities. Slowly changing levels may indicate the need for minor to major mitigation regarding physical, chemical, or biological practices in the watershed.

Significance/Justification: Major fluctuations in these parameters can lead to serious consequences downstream, including fish kills and eradication of all aquatic biota.

Proposed Metrics: The pH will be represented by the negative logarithm of the hydrogen ion concentration, dissolve oxygen will be measured in parts per million, specific conductance will be measured in micromohs/cm, and temperature in degrees Celsius (Boyd, 1979).

Prospective Method(s) and Frequency of Measurement: Standardized methods have been developed for measurement of these parameters in freshwater (APHA et al. 1992). Frequency of measurement may be determined at a later date, depending on park management objectives (Rosenberg and Resh 1993).

Limitations of Data and Monitoring: Values can change quickly, and some diurnal fluctuations can be expected. Both natural anomalies and anthropogenic activities can cause these fluctuations, and are not often predictable (Boyd 1979).

Key References:

American Public Health Association, American Water Works Association, and Water Environment Federation (APHA et al.). 1992. Standard Methods for the examination of water and wastewater. 18th Ed. A. E. Greenberg, L. S. Clesceri, A. D. Eaton, and M. A. H. Franson, Eds. American Public Health Association, 1015 Fifteenth Street, Northwest, Washington, DC. 20005.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station. Auburn, AL. 359 pp.

Rosenberg, D. M., and V. H. Resh. 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. D. M. Rosenberg and V. H. Resh, Eds. Chapman & Hall. New York, NY. 488 pp.

Related Environmental Issues and Linked Vital Signs: Very closely linked to surface water hydrology, weather and climate, air chemistry, groundwater hydrology, and water quality-expanded parameters.

Overall Assessment: Fluctuation possibilities loom large depending on weather and climate and surface water hydrology. Temperature readings may be available without cost. Frequency of data collection will depend heavily upon overall management objectives.

Level 1 – Water

Level 2 – Water Quality

Level 3 – Water Quality – Expanded Parameters

Brief Description: Measurement of water quality parameters beyond the Core Parameters.

Significance/Justification: Many different inorganic and organic chemicals and compounds are capable of entering river systems and causing problems for aquatic biota. There are also physical and biological parameters which can cause problems in the riverine ecosystem. This sampling will serve to monitor such potential stressors to such ecosystems.

Prospective Metrics: Cations (Ca, Mg, Na, K), anions (PO_4, NO_2, Br, SO_4, Cl, acid neutralizing capacity), turbidity, suspended sediments, BOD, COD, alkalinity, N & P compounds, chlorophyll a, VOC's, SVOC, pesticides, PCB's, trace metals, etc. Other organic and inorganic substances, enteric viruses, fecal coliform bacteria (total coliform enterococci, fecal *Streptococci* groups, *E. coli*), *Giardia*, etc.

Prospective Method(s) and Frequency of Measurement: Standardized methods have been developed for measurement of these parameters in freshwater (APHA et al. 1992). Frequency of measurement may be determined at a later date, depending on park management objectives (Rosenberg and Resh 1993).

Limitations of Data and Monitoring: There are always intervals between sampling when fluctuations in parameter values may exist which may not be recorded. Values can change quickly, and some diurnal fluctuations can be expected. Both natural anomalies and anthropogenic activities can cause these fluctuations, and are not often predictable (Boyd 1979).

Key References:

American Public Health Association, American Water Works Association, and Water Environment Federation (APHA et al.). 1992. Standard Methods for the examination of water and wastewater. 18th Ed. A. E. Greenberg, L. S. Clesceri, A. D. Eaton, and M. A. H. Franson, Eds. American Public Health Association, 1015 Fifteenth Street, Northwest, Washington, DC. 20005.

Boyd, C. E. 1979. Water quality in warmwater fish ponds. Auburn University Agricultural Experiment Station. Auburn, AL. 359pp.

Rosenberg, D. M., and V. H. Resh. 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. D. M. Rosenberg and V. H. Resh, Eds. Chapman & Hall. New York, NY. 488 pp.

Related Environmental Issues and Linked Vital Signs: Very closely linked to surface water hydrology, weather and climate, air chemistry, groundwater hydrology, and water quality-core parameters.

Overall Assessment: Fluctuation possibilities are possible depending on weather and climate and surface water hydrology. Temperature readings may be available without cost. Frequency of data collection will depend heavily upon overall management objectives.

Level 1 – Biological Integrity

Level 2 – Focal Species or Communities

Level 3 – Aquatic Macroinvertebrates - Water Quality Suite

Brief Description: Monitor composition of benthic macroinvertebrate communities to assess natural and human-induced alterations to riverine systems.

Significance/Justification: Benthic macroinvertebrate assemblages have long been recognized as measurable indices of localized conditions because of their complex life cycles lasting a year or more, their mostly sedentary behavior, and their ability to react in predictable ways to human influences on aquatic systems (Bilger et al. 2005). Early efforts to document water quality using invertebrates focused mainly on organic pollutants, but techniques have evolved into multi-disciplined approaches that remain faunistic but also include habitat and geomorphic analysis. Recent efforts are concerned with understanding native fauna and managing waters for maximum biological quality, including taking corrective action in response to system degradation (Cairns and Pratt, 1993).

Proposed Metrics: Multimetric index.

Prospective Method(s) and Frequency of Measurement: Benthic index of biotic integrity at genus level that incorporates components sensitive to sedimentation, organic enrichment, toxic chemicals, and flow alteration (Karr and Chu, 1999). Possible use of functional descriptions of invertebrate communities across species (Gayraud et al. 2003).

Limitations of Data and Monitoring: Effective multimetric indices depend on an appropriate classification system, the selection of metrics that give reliable signals of river condition, systematic sampling protocols that measure those biological signals, and analytical procedures that extract relevant biological patterns. Requires accurate regional taxa lists and accompanying environmental tolerances and functional characteristics (see Bilger et al. 2005).

Key References:

Barbour, M. T., J. Gerrittsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in streams and wadeable rivers – periphyton, benthic macroinvertebrates, and fish (2nd ed.). U.S. Environmental Protection Agency, Office of Water. EPA 841-B-99-002. Washington, DC.

Bilger, M. D., K. Riva-Murray, and G. L. Wall. 2005. A checklist of the aquatic invertebrates of the Delaware River Basin, 1990–2000. U.S. Geological Survey. Data Series 116. 29 pp.

Cairns, J., Jr., and J. R. Pratt. 1993. A history of biological monitoring using benthic macroinvertebrates. *In* Rosenberg, D. M. and V. H. Resh (eds.). Freshwater biomonitoring and benthic macroinvertebrates. Chapman and Hall. New York, NY. Pp. 10–27.

Gayraud, S., B. Statzner, P. Bady, A. Haybachp, F. Scholl, P. Usseglio-Polatera, and M. Bacchi. 2003. Invertebrate traits for the biomonitoring of large European Rivers: an initial assessment of alternative metrics. Freshwater Biology 48:2045–2064.

Karr, J. R. 1999. Defining and measuring river health. Freshwater Biology 41:221–234.

Karr, J. R., and E. W. Chu. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Island Press. Washington, DC.

Related Environmental Issues and Linked Vital Signs: Macroinvertebrate communities are a biological endpoint affected by most riverine primary predisposing and inciting factors such as climate, river geomorphology, surface and groundwater hydrology, and water chemistry. Macroinvertebrate communities may also be affected by invasive species (see Gayraud et al. 2003).

Overall Assessment: Biological indicators such as benthic macroinvertebrates provide the most integrative assessment of river condition but can be costly and inconclusive if conducted incorrectly.

Level 1 – Biological Integrity

Level 2 – Focal Species or Communities

Level 3 – Fish Communities

Brief Description: "Fish Communities" refers to measures of the structure and composition of the fish populations.

Significance/Justification: Fish are important components of most healthy riverine ecosystems, occupying the top of the food web. Moreover, unlike other groups, the condition of fish populations is frequently of interest to the broad public due to their importance in terms of recreation and food. Even more importantly, fish have numerous characteristics that are advantageous from a biological monitoring and assessment perspective, which include: 1) they are relatively easy to collect and identify; 2) because they are among the longest lived species in streams and mobile, they are good indicators of long-term effects and broad habitat conditions; 3) the life histories and environmental requirements of most species are well known; and 4) they occupy positions throughout the aquatic food web and, thus, provide an integrateive view of watershed conditions (Karr 1986; Barbour et al. 1999). In addition, unlike aquatic macroinvertebrates and periphyton assemblages that exhibit wide natural variation seasonally, the relative abundance of fish species (excluding young-of-the-year individuals) remains relatively stable. As a result, fish sampling can occur over much broader sampling windows which allows more flexibility in terms of logistics.

Proposed Metrics: Two approaches to drawing inferences regarding ecological condition of streams are proposed. The first is a multivariate analysis approach that compares community composition within a stream reach from one time to the next based on the relative abundance of component taxa. This method uses traditional multivariate ordination or classification techniques such as Principal Components Analysis, Canonical Correlation Analysis, Discriminant Analysis, or K-means clustering (see Gauch 1982 for detailed synthesis of multivariate methods), and is useful because it allows evaluations of overall structure (groupings of species) as well as changes in individual species. The second approach is the multi-metric approach that has become increasingly common for bioassessments involving fish, especially in North America. This approach involves the calculation of numerous individual assemblage metrics, combining the information into a single score (i.e., index of biotic integrity or IBI), and comparison of the combined index score with the range of scores expected for streams of similar type in the region (Karr et al. 1986). Both integrated scores and values for individual metrics can be evaluated and monitored and have been shown to be useful assessment tools.

The metrics selected for inclusion into multi-metric approach depend on stream type and geographic region because expected scores for individual metrics vary in ecologically healthy streams. However, metrics usually include measures of species richness and composition, trophic composition, and fish abundance and condition (Karr 1987). Moreover, indices of biotic integrity (IBIs) have been developed for most regions of the country and many stream types (e.g., cold water streams versus warm water streams, highland streams versus coastal or piedmont streams, high-gradient versus low-gradient, etc.) (see Miller et al. 1988 for review).

Particularly relevant to ERMN are IBIs developed and tested for highland streams in Maryland (Roth et al. 1998), the mid-Atlantic highlands (McCormick et al. 2001), and for small, cool-water streams in the Appalachian Plateau of West Virginia (Leonard and Orth 1986).

Prospective Method(s) and Frequency of Measurement: Because most species reproduce only once a year, populations tend to be stable throughout the year (if young-of-the-year fish are not considered). As a result, a single sampling during the relatively long period of base flow conditions is all that is required to adequately assess fish assemblages within a stream reach. Electrofishing has been shown to be the most effective sampling technique for collecting information on the broad fish community. Depending on stream size and depth profiles, a DC current backpack electroshocking unit, or a towable Pram electroshocking unit, operated by a team of either two or three individuals experienced with electoshocking techniques, is needed to effectively sample small and mid-sized wadeable streams. The team should include a fish biologist with knowledge of the regional fauna so that species-level identifications can be made in the field. Alternatively, samples would need to be returned to the lab, which not only is significantly more costly and time-consuming, but also can impact the resident fauna. Detailed methods for fish shocking protocols are described in Barbour et al. (1999).

Limitations of Data and Monitoring: Because of natural barriers to movement, like waterfalls and beaver dams, fish assemblages are naturally species-poor in many smaller streams. For example, many of the streams draining steep terrains in Delaware Water Gap National Recreation Area support only a single species of fish (Ross et al. 2003), making assemblage-level assessments meaningless. Thus, ecological assessments using fish should probably be limited to mid-reach streams. In addition, fish tend to be poor indicators of intermittent stresses because they will move from stream reaches during stressful times but return when conditions improve. Finally, relative to other groups, fish sampling requires more expensive and labor-intensive methods to effectively survey.

Key References:

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, DC.

Gauch, H. G., Jr. 1982. Multivariate Analysis in Community Ecology. Cambridge University Press. NY. 298 pp.

Karr, J. R. 1986. Assessing biological integrity in running waters: A method and its rationale. Illinois Natural History Survey Special Publication 5. Illinois Natural History Survey. Champaign, IL.

Leonard, P. M., and D. J. Orth. 1986. Application and testing of an index of biotic integrity in small, coolwater streams. Transactions of the American Fisheries Society 115:401–414.

McCormick, F. H., R. M. Hughes, P. R. Haufmann, A. T. Herlihy, D. V. Peck, and J. L. Stoddard. 2001. Development of an index of biotic integrity for the Mid-Atlantic Highlands region. Transactions of the American Fisheries Society 130:857–877.

Miller, D. L., P. M. Leonard, R. M. Hughes, J. R. Karr, P. B. Moyle, L. H. Schrader, B. A. Thompson, R. A. Daniel, K. D. Fausch, G. A. Fitzhugh, J. R. Gammon, D. B. Halliwell, P. L. Angermeier, and D. J. Orth. 1988. Regional applications of an Index of Biotic Integrity for use in water resource management. Fisheries 13:12–20.

Ross, R. M., R. M. Bennett, C. D. Snyder, J. A. Young, D. R. Smith, and D. P. Lemarie. 2003. Influence of eastern hemlock (Tsuga Canadensis L.) on fish community structure and function in headwater streams of the Delaware River basin. Ecology of Freshwater Fish 12:60–65.

Roth, N., M. Southerland, J. Chaillou, R. Klauda, P. Dazyak, and S. Stranko. 1998. Development of a fish index of biotic integrity. Environmental Monitoring and Assessment 51:89–106.

Related Environmental Issues and Linked Vital Signs: Fish assemblages are influenced by a wide range of instream, riparian, and landscape features that vary naturally and are themselves altered by human disturbance. In particular, stream channel characteristics, water quality, stream hydrology, riparian vegetation, periphyton, landscape pattern, and land use change are all linked to fish assemblage measures.

Overall Assessment: Fish assemblage measures can be an excellent indicator of ecological condition in streams if the resident fauna is well known and reference conditions have been documented. Fish sampling is more expensive than for other groups such as periphyton and macroinvertebrates, but it is easier to effectively characterize fish assemblages. Moreover, because they are longer lived, fish assemblage metrics provide a better indicator of long-term trends in ecological condition than other groups.

Level 1 – Biological Integrity

Level 2 – Focal Species or Communities

Level 3 – Riparian Plant Communities

Brief Description: Riparian plant communities are particularly vulnerable to invasive species because their linear nature exposes them to large areas containing potential invaders (Simberloff et al. 2005). The range of conditions of riparian zones varies widely in riverine watersheds because site conditions range from those with saturated soils to soils that are well-drained and infrequently flooded. Given this range of conditions, there is little selective pressure against any particular group of species with narrow habitat preferences. Species that are dispersed by wind or water can most easily invade, and roads and trails provide additional corridors for effective dispersal. Further, disturbance factors, such as the development of point bars on rivers, opening of forest canopies by storms, and alteration of floodplains by beaver activity tend to expose sites to colonization of invasives. Once established, invasive species may compete for light, water, and nutrient resources, all of which are generally abundant in riparian areas.

Significance/Justification: Most plant species classified as invasive tend to concentrate along forest edges and other areas of disturbance (Walker and Smith 1997; Woods 1997). There are few tree and shrub species, such as *Ailanthus altissima* (tree-of-heaven) and *Eleagnus angustifolia* (Russian olive), that may form monospecific stands (Miller 2004). Once established, it is difficult for native trees to compete with them. Several shrubs and vines can form dense growths in disturbed areas and forest edges, including *Ligustrum sinense* (Chinese and other privets), *Lonicera* spp. (Japanese and other honeysuckles), *Celastrus orbiculatus* (oriental bittersweet), and *Pueraria montana* (kudzu). *Microstegium virmineum* (Japanese stiltgrass) is a grass that can become particularly abundant in along streambanks and in floodplains. It is shade-tolerant and a prolific seeder, and thus easily disperses. Based on its capacity to out-compete other groundcovers, especially in shade, the species has the capacity to suppress other herbaceous species. *Polygonum cuspidatum* (Japanese knotweed) is becoming increasingly prevalent. *Lythrum salicaria* (purple loosestrife) and *Phragmites communis* (common reed) are obligate wetland plants found in some riparian settings (Galatowitch et al. 1999). Global warming may expand the ranges of many southern invasives into riparian areas of the ERMN. Since the rate of expansion of plant species is not predictable from ecological traits (Clark et al. 1998), empirical data are needed to follow trends in real time.

Proposed Metrics: Classification and inventory are the first steps in the assessment of any natural resource. If an agreed-upon list of potentially problematic species can be developed and vulnerable sites for invasion within and surrounding each of the NPS lands are identified, this information can provide the basis for an inventory to track the occurrence and spread of invasive species. Baseline data generally are not available.

Prospective Method(s) and Frequency of Measurement: Annual surveys of the vulnerable sites in and around the ERMN sites would provide information on trends and conditions for riparian invasive plants. Since many invasive species tend to disperse along highways and trails, sampling sites could be located where these conduits cross stream channels. Abundance

measures should be developed to characterize the areal distribution and patchiness. A recent protocol has been developed to standardize the assessment of nonnative invasive species (Morse et al. 2004).

Limitations of Data and Monitoring: To track changes over time, monitoring sites need to be established to illustrate where invasive species are absent as well as where they are present. Little training would be needed to recognize invasives, because there are few of them, most are easily identified, and many are already familiar to most naturalists.

Key References:

Clark, J. S., C. Fastie, G. Hurtt, S. T. Jackson, C. Johnson, G. A. King, M. Lewis, J. Lynch, S. Pacala, C. Prentice, E. W. Schupp, T. Webb, and P. Wyckoff. 1998. Reid's paradox of rapid plant migration. BioScience 48:13–24.

Galatowitsch, S. M., N. O. Anderson, and P. D. Ascher. 1999. Invasiveness in wetland plants in temperate North America. Wetlands 19:733–755.

Miller, J. H. 2004. Nonnative Invasive Plants of Southern Forests. USDA Forest Service. Southern Research Station. General Technical Report SRS-62. Asheville, NC.

Morse, L. E., J. M. Randall, N. Benton, N. Hierbert, and S. Lu. 2004. An invasive species assessment protocol: evaluating nonnative plants for their impact on biodiversity, version 1. NatureServe. Arlington, VA. (Accessed 25 April 2005.) Available at http://www.natureserve.org/library/invasiveSpeciesAssessmentProtocol.pdf.

Walker, L. R., and S. D. Smith. 1997. Community response to plant invasion. Pp. 69–86 *in* J. O. Luken and J. W. Thieret, editors. Assessment and Management of Plant Invasions. Springer-Verlag. New York, NY.

Woods, K. D. 1997. Community response to plant invasion. Pp. 56–68 *in* J. O. Luken and J. W. Thieret, editors. Assessment and Management of Plant Invasions. Springer-Verlag. New York, NY.

Related Environmental Issues and Linked Vital Signs: Climate change could expand the range northward of a number of exotic species that are presently confined to warmer climates.

Overall Assessment: There are few examples of invasive species causing the extirpation of other plant species, except on a small, site-specific basis. Often, invasives such as kudzu (*Pueraria lobata*) seem prevalent because they occupy disturbed areas along forest edges where they are conspicuous. Areas with full canopy cover are unlikely to support most invasives, with *Microstegium vimineum* (Japanese stiltgrass) an exception because of its shade tolerance. It is recommended that a modest inventory program be set up so that the spread of exotic species along riparian corridors is noted. It could be coordinated with a program to follow the phenology of plants.

Level 1 – Human Use

Level 2 – Point Source Human Effects

Level 3 – Aquatic Bioaccumulation of Toxins / Contaminants

Brief Description: Monitor bioaccumulation of contaminants to assess toxicity levels in riverine predators. Significant as indicator of cumulative toxicity within aquatic organisms, early warning for terrestrial predators such as bald eagles, and monitoring for human consumptive use restrictions.

Significance/Justification: Fishes at or near the top of the food chain have long been recognized as predisposed to bioaccumulation of toxins in the environment (Hickey et al. 1966). These fishes are very often targeted by recreational fishermen, as they include trout, bass, and other popular species. Such fishes tend to concentrate airborne toxins such as mercury (Josephson 1976; Kurland et al. 1960). Benthic freshwater macroinvertebrates are most commonly used to monitor metals and organic contaminants such as PCB's (Rosenberg and Resh 1993). Bioaccumulation is used when ambient concentrations are too low for direct analysis (Graney et al. 1983). Given recreational activities in NPS lands include fishing, it is important to know of any related risk to public health.

Prospective Metrics: Bioconcentrations in parts per million (ppm) and parts per billion (ppb).

Prospective Method(s) and Frequency of Measurement: Fish samples will be collected twice yearly using gill nets and/or beach seines. Benthic freshwater macroinvertebrate samples will be collected with kick nets. Tissue samples will be analyzed using gas chromatography and atomic absorption spectrophotometry.

Limitations of Data and Monitoring: Migratory fishes captured may reflect concentrations from other locations. Requires standardized methods.

Key References:

Graney, R. L. Jr., D. S. Cherry, and J. Cairns Jr. 1983. Heavy metal indicator potential of the Asiatic clam (*Corbicula fluminea*) in artificial stream systems. Hydrobiol. 102:81–88.

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Kurland L. T., Faro S. N., and H. Siedler H. 1960. Minamata disease. World Neurology 1:370–395.

Rosenberg, D. M., and V. H. Resh. 1993. Freshwater Biomonitoring and Benthic Macroinvertebrates. D. M. Rosenberg and V. H. Resh, Eds. Chapman & Hall, Inc. New York, NY. 488 pp.

Related Environmental Issues and Linked Vital Signs: Bioaccumulation is the endpoint of pollutants that are acquired by groundwater hydrology, surface water hydrology, and air chemistry.

Overall Assessment: Bioaccumulation of toxins data will give managers the ability to make recommendations regarding personal consumption of fish from their jurisdictional waters.

Level 1 – Air and Climate

Level 2 – Weather and Climate

Level 3 – Weather and Climate

Brief Description: Weather and climate have the potential to affect the distribution of all species. The present geographical distribution of species can be presumed to be a consequence of past redistributions, as weather and climate have changed over time leading up to the present. However, species redistributions have been shown to occur at different rates, as exemplified by different rates of latitudinal movement of tree species distributions following the last glacial maximum in North America (Davis 1987). This argues for regarding species movements during climate change individually, and predicting these movements based on the ecological tolerances of each species. In contrast, all species are constrained to some extent by the ecological relationships with other species. Species with commensal, predator-prey, or other "symbiotic" interrelationships are likely to have coordinated redistributions, and, thus, not follow individualistic patterns. Any models taking into account the effects of climate change must recognize this duality. Species at the northern or southern limits of distributions are the ones that could serve as indicators of response to climate change. A 1.5–4.5°C (34.7–40.1°F) warming by the end of the twenty-first century, as indicated by Overpeck et al. (1991), could lead to a shift of southern species to the north (Solomon and Kirilenko 1997). Species isolated geographically to the highest altitudes, such as red spruce in the southern Appalachians, could be extirpated locally (Adams et al. 1985).

Significance/Justification: Weather and climate are but one set of factors representing the multidimensional niche of species, and, thus, their current distributions. The geographical redistribution of species may have cascading effects on other dependent species. To the extent that some tributary watersheds occur at the highest altitudes, high altitude distributions are expected to be the most vulnerable. Likewise, organisms at the fringes of climatically restricted population distributions are the most vulnerable to additional stressors caused by human activities. Such species may serve as indicators of these interactions (De Groot et al.1995). As described elsewhere, Mahan (2004) provides lists of plants, vertebrates, and communities of special concern in the New River Gorge, some of which may be among the first to respond to climate change.

Proposed Metrics: *Prospective Method(s) and Frequency of Measurement*: Two groups of species deserve monitoring: those that have rather distinct north and south boundaries and those that are restricted to high altitudes. For the former, population abundances and other indices of population vitality can be measured at the boundaries of the species distributions. For the latter, a similar approach may be taken for altitude. As with any measurement, and especially climatically related indicators, interannual variation can be a critical component in interpreting the relevance of long-term data to species distribution. For example, weather extremes of precipitation, temperature, storminess, daytime vs. nighttime averages, etc., may each have influences on populations locally and over short-time intervals.

Limitations of Data and Monitoring: Most species of interest will be ones distributed outside of boundaries of NPS control. Consequently, any monitoring program must be driven by the distribution of the chosen indicator species rather than only the distribution in lands under federal jurisdiction of the NPS.

Key References:

Adams, H. S., S. L. Stephenson, T. J. Blasing, and D. N. Duvick. 1985. Growth-trend declines of spruce and fir in mid-Appalachian subalpine forests. Environmental and Experimental Botany 25(4):315–325.

Davis, M. B. 1987. Invasion of forest communities during the Holocene: Beech and hemlock in the Great Lakes Region. Pp. 373–393 *in* A. J. Gray, M. J. Crawley, and P. J Edwards (editors). Colonization, Succession, and Stability. Blackwell Publishers. Oxford, UK.

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Hicks, R. R., Jr. 1998. Ecology and Management of Central Hardwood Forests. John Wiley and Sons. NY. 412 pp.

Mahan, C. G. 2004. A Natural Resource Assessment for the New River Gorge National River. U.S. Department of Interior. NPS Technical Report NPS/NER/NRTR—2004/002. 129 pp.

Overpeck, J. T., P. J. Barlein, and T. Webb III. 1991. Potential magnitude of future vegetation change in eastern North America: comparisons with the past. Science 254(5032):692–695.

Solomon, A. M., and A. P. Kirilenko. 1997. Climate change and terrestrial biomass: What if trees migrate? Global Ecology and Biogeography Letters 6(2):139–148.

Related Environmental Issues and Linked Vital Signs: Weather and climate directly affect a number of other ecosystem attributes, especially related to sensitive and T&E species, biodiversity, etc. Because climate does not act in a vacuum, other vital signs, such as levels of atmospheric pollution, may interact with climate to affect organisms. Indirect effects may occur, such as the enabling of invasive species and loss of focal species or communities.

Overall Assessment: Climate plays a fundamental role in terrestrial ecosystems, and particularly tributary watersheds at high altitudes. Therefore, climatic changes, and associated alterations in weather patterns, have the potential to change the distribution of species and associated communities. Current models of climate change are notoriously general and geographically imprecise. In some ways, changes in species distribution may more effectively indicate climate change than the use of climate change projections to predict future distributions of species. Regardless, a great deal of uncertainty will accompany either approach, and it is the accumulation of multiple trends of many indicators that will ultimately be the most compelling evidence for change.

Level 1 – Landscapes (Ecosystem Patterns and Processes)

Level 2 – Landscape Dynamics

Level 3 – Land Cover / Land Use Change and Landscape Pattern

Brief Description: "Landscape Pattern" refers to the states and distribution of the various dominant cover types, as they exist within a landscape mosaic. In addition to the current pattern, historic patterns (Braun 1950) should be considered, as well as trends and changes in landscape patterns. These changes can be useful indicators of the natural and human-caused forces acting upon the landscape (Alig and Butler 2004). Turner et al. (2003) examined the landscape-level changes in the Appalachian region (including much of the ERMN) and found that during the four-decade interval, from 1950–1990, the amount of forest cover increased and fragmentation decreased, but they cautioned that recent housing development in the region may offset many of these gains. Human impacts are a critical element in the changing landscapes of the ERMN and Ritters et al. (2000) indicate that land cover information provides a mechanism to place humans into ecological assessments.

Significance/Justification: Human activities are primary drivers in landscape-level changes in the Appalachians (Ritters et. al. 2000). Historical occurrences such as agricultural clearing, agricultural abandonment, timbering, surface mining, forest fire control, predator eradication, hunting regulation, insect and disease introductions, and urban sprawl are all examples of how humans have contributed to landscape-level changes over the last hundred and fifty years. ERMN parks are, in effect, islands within an ever-changing mosaic of land, and changes outside the ERMN parks can potentially affect the ecological properties within the parks (Brosofske et al. 1999). Changes are particularly relevant to riverine watersheds where human activities outside of NPS land can affect downstream ecosystems located within NPS land. Roads have a particularly significant fragmenting effect on terrestrial ecosystems (Forman 2000; Trombulak and Fressell 2004). Because land-use patterns surrounding the ERMN are changing and these changes have the potential for altering the ecological characteristics within the parks, it is important that park managers be aware of this process and how it is likely to affect them.

Proposed Metrics: Landscape ecology is a field that uses spatial analysis methods to evaluate the pattern of various land cover types at different spatial scales. Metrics include the proportion of a given landscape occurring in a particular cover type and indices of patchiness, fragmentation, connectivity, etc. In addition, changes in linear features, such as streams and riparian zones, while not occupying large surface areas, have a profound effect on aquatic resources. These metrics can be used to compare among landscapes or to observe temporal changes in a single landscape.

Prospective Method(s) and Frequency of Measurement: Spatial analysis methods begin with imagery (aerial photography, satellite images, etc.) and databases (USGS topographic information, ownership, etc.). Image information requires interpretation in order to determine what the visual information represents. Interpretation can be facilitated by image enhancing methods, such as digital color transformations. The resulting information is used to create a geographic information system (GIS) that incorporates multiple layers of spatial information,

such as land use, ownership, cover type, topography, etc. Software packages are available that provide powerful tools for organizing, interpreting, and displaying the information. Spatial statistics can be used to analyze the data (Gardner et. al. 1987), and models constructed using information from known landscapes can be used to predict the states of other landscapes (Trombulak and Frissell 2004).

Limitations of Data and Monitoring: A substantial amount of landscape-level information currently exists, much of which is public record, and therefore inexpensive to acquire. The problem with many available sources of images or spatial data is that they must be adapted to the specific use required (e.g. ERMN parks). The detail, scale, and type of imagery may not suit the specific purpose of the ERMN, requiring that new and expensive data need to be gathered. The development of a system-wide GIS can be a daunting task, requiring that either contractors or trained NPS employees complete the work. Furthermore, as Li and Wu (2004) warn, landscape analysis often falls short of meeting its high expectations due to conceptual flaws in pattern analysis, inherent limitations of landscape indices, and improper use of pattern indices.

Key References:

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Trombulak, S. C., and C. A. Frissell. 2004. Review of ecological effects of roads on terrestrial and aquatic communities. Conservation Biology 14(1):18–30.

Turner, M. G., S. M. Pearson, P. Bolstad, and D. N. Wear. 2003. Effects of land-cover change on spatial pattern of forest communities in the Southern Appalachian Mountains (USA). Landscape Ecology 18:449–464.

Related Environmental Issues and Linked Vital Signs: Landscape pattern is related to many environmental issues, particularly ones having to do with anthropogenic effects such as pollution, land use, settlement, etc. Landscape patterns are linked with almost all the vital signs

identified for ERMN parks. Atmospheric and climatic patterns vary across the landscape, and these factors, in turn, create patterns in vegetation and land use. Geology and soils also contribute to landscape patterns, as well as do hydrologic features. Because human activities often are involved in the introduction of invasive species, and human habitation is part of the landscape pattern, the pattern of introduction of invasive species often follows patterns of human activity (transportation, settlement, etc.). Plant and animal communities are specifically adapted to their environment, which changes across the landscape. Visitor usage can locally alter an ecosystem; thereby, imposing an anthropogenic pattern on the landscape. Finally, bio-productivity and nutrient dynamics are specifically linked to the landscape pattern. In short, the pattern that exists on the landscape is a reflection of the sum of the abiotic, biotic, and anthropogenic factors that interact over it.

Overall Assessment: Landscape pattern is a result of the interaction of numerous factors (historic and present). ERMN parks are themselves part of a larger landscape and are affected by actions that take place beyond their boundaries. The discipline of landscape ecology has been developing in recent years and involves using imagery, data, technology, and statistical tools to analyze and interpret spatial information. ERMN managers can use these methods to assess current conditions in their parks as they relate to the larger landscape. Use of this tool may enable managers to anticipate changes and take remedial actions, when necessary.

As the nation's primary conservation agency, the Department of the Interior has responsibility for most of our nationally owned public land and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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