Section 3. Ecological Concepts Underlying Environmental Benefits Analysis

3.1 Section Objectives and Background

3.1.1 Objectives

The objective of this section is to summarize ecological concepts of potential relevance for characterizing and evaluating ecosystem restoration outputs. It considers the types of ecosystem outputs and indicators of environmental benefit that might be useful for Corps plan formulation and evaluation, including the possibility that there may be some inclusive non-monetary measure of environmental benefit that may have wide applicability for ecosystem restoration planning. In addition, it addresses the scale and character of natural ecological inputs from the influential ecosystem environment (the system context) that generally determine the ecosystem structure and functions that need to be considered for predicting ecosystem outputs. A secondary intent is to provide a *conceptual basis* to aid in the selection and development of physical and mathematical models useful for plan formulation and evaluation of ecosystem outputs indicative of environmental benefit. Relevant model types are discussed in Section 4.

The discussions within this section include:

- Corps policy that contributed to determination of ecological concept relevancy.
- Ecological concepts, beginning with *ecosystem structure and function*, which is the focus of Corps restoration purpose and definition of *ecological resources*.
- The concept of *natural ecosystem service*, as conceived primarily by ecologists and ecological economists, and attempts to describe "*naturalness*" in the concepts of *natural and cultural integrity*, and related concepts of *ecosystem health* and *sustainability.*
- The broadly stated concepts relevant to output characterization that are pertinent for restoration formulation and evaluation, including *biodiversity; ecosystem self-regulation, resilience* and *sustainability; ecosystem production* and *biomass*; and *ecosystem materials flow and cycling* (with hydrologic cycling as a special case).
- An important culminating discussion of the often different responses of ecosystem function and structure to natural and managed restoration process leads into a summary discussion of the *roles of local and global biodiversity* as benefit indicators for plan formulation and evaluation.
- A brief description of the character and scale of ecosystem inputs necessary for consideration in comprehensive formulation and evaluation methods and models.

3.1.2 Policy Indicators of Ecological Concept Relevance

Many ecological concepts most relevant to environmental benefits analysis in Corps ecosystem restoration planning are indicated by Corps policy. Much of the relevant policy has been summarized in Chapter 1 and 2. A few additional points are summarized here.

The concept of environment Corps policy limits *evaluation* of environmental improvement from ecosystem restoration to *ecological* resource quality. It clearly excludes cultural and aesthetic attributes of the environment as it is more inclusively defined in the P&G (WRC 1983). Moreover, the ecological resource quality to be considered “is a function of improvement in habitat quality and/or quantity”. The concept of habitat in Corps policy is defined by the needs of living inhabitants—that is, the inhabitants comprise the resource quality generated by habitat improvement. Thus the ecological indication of resource quality is found in the inhabitants—the species and communities—not the habitat itself. Thus the Corps formulates for habitat as defined by the needs of the inhabitants and evaluates plans based on the confidence that the habitat will become inhabited once it is provided. This is the Achilles heel of many existing planning methods and models.

While habitat improvements may affect non-living outputs from the ecosystem (e.g., water supply, water quality, carbon dioxide emissions, sediment export), they are not among the significant resources that justify a restoration investment. However, the responses of nonliving outputs to restoration also need to be considered for their effect on the total benefit realized by restoration plans. The completeness with which this is done may determine the degree of concern associated with the NRC (1999a) fear that habitat-based methods, when used alone, may fail to consider all of the national interests.

The living resources targeted for ecosystem restoration should contribute to the “net quantity and/or quality of desired ecosystem resources" both “in the planning area and in the rest of the Nation”. Thus the scope of planning method consideration extends to the entire ecosystem condition in the U. S., not just the local fraction of the ecosystem existing in the project area or environs. Because local sites in ecosystems often express widely different attributes from much of the ecosystem, the larger perspective is important for determining the degree of human effect and resource degradation that has occurred in the ecosystem. Ecological resources may be locally scarce, but nationally abundant. The national perspective sets a standard for judging the scarcity of ecosystem resources, which is an important consideration for determining its social significance.

The outputs from ecosystem restoration plans are to indicate a *significant* change in *significant* resource condition to a *less degraded* and *more natural condition.* “Restored ecosystems should mimic, as closely as possible, conditions which would occur in the area in the absence of human changes to the landscape and hydrology”. The term landscape refers to the full set of surrounding ecosystem conditions that influences the project ecosystem condition. Another intent is “to partially or fully reestablish the attributes of a naturalistic, functioning, and self-regulating system” to assure as long as possible the long-term continuity of improved resource condition. Thus, whatever more natural (or naturalistic) condition is established in support of significant living resources, the ideal condition is functionally self-regulating.

To help planners focus on the remote as well as proximal influences determining self regulation and long-term persistence in the project area, including the entire community-habitat complex, policy emphasizes the importance of viewing the project area as a dependent subsystem in a larger systems context. "Ecosystem restoration projects should be formulated in a systems context to improve the potential for long-term survival of aquatic, wetland, and terrestrial complexes as self-regulating, functioning systems." The Corps Environmental Operational Principles reinforce this notion of long term continuity or beneficial results, and introduces related concepts: "Strive to achieve environmental sustainability: An environment maintained in a healthy, diverse and sustainable condition necessary to support life". The closely related ecological concepts of *ecosystem integrity* (including both natural and cultural integrity) and *biodiversity* pertain especially to policy concepts of naturalness and *sustainability*, and the concept of ecosystem *self-regulation* is an especially critical master-function.

It is possible, if not likely, that in some cases, a more natural condition (whatever results from removing human effect) is in itself the ecological output of significance. According to Corps policy, that increased naturalness needs to be reflected in the living organisms comprising the significant resources and the habitat through which those resources are to be restored. Based on past restoration motivations, however, increasing the naturalness of the habitat-community complex may not regain specific resources of significance, especially when the restoration is only partial and the targeted resources are among the rare species in the ecosystem.

The existing understanding of ecosystems described in this section suggests that common conceptual and mathematical models of ecosystem naturalness will most confidently predict reestablishment of all ecosystem resources of significance only when full restoration of a natural state is achieved throughout the ecosystem. The concept of ecological *resilience* is especially relevant to this judgment because of what it has to say about differential responses of function and structure to natural or engineered restoration, depending on system context, degree of alteration, and intensity of stress. This issue is critical because human effects are so pervasive and persistent, in large part because they are desirable effects, that restoration to a fully natural ecosystem state is improbable at best in most ecosystems.

Policy identifies a number of ecological concepts of high relevancy to environmental benefits analysis for ecosystem restoration projects. These include the interrelated concepts of natural ecosystem *structure, function, dynamic process, ecosystem integrity* (both natural and cultural*), biodiversity, self-regulation, resilience, functional stability, functional redundancy, sustainability, ecosystem health, production, materials cycling* (including the *hydrologic cycle), landscape* and related ideas. To the extent that these interrelated concepts can reflect the effects of human impacts on ecosystems and the effects of restoration on human perceptions of significant change, they may be considered as important attributes of *environmental quality* associated with ecosystem naturalness and resources of significance. Some of these ecological concepts are more thoroughly developed than others. While many questions remain about concept validity and practical applications, the sum forms a theoretical basis for the formulation for and the evaluation of ecosystem restoration benefits.

3.2 The Ecosystem Source of Human Service

The concept of ecosystem service is a useful entry way to defining the relevancy of ecological concepts to environmental benefits analysis. Ecological function and structure are the traditional subjects of ecological investigation, but their relevancy to society and public policy often gets lost in the science. The combined growth in human population and per capita human effect is rapidly changing natural ecosystem function and structure, with potentially threatening consequences that continues to concern many ecologists and some social scientists. To bridge the gap between ecological science and policy applications, a growing group of ecologists and social scientists (Daily 1997, Daily et al. 1997) have developed a concept of natural ecosystem service to humanity. This recent development builds on a long history of renewable natural resources management based in ecological science and resource utility. With respect to the connection between ecosystem function and service, Daily (1997) states:

> "In addition to the production of goods, ecosystem services are the actual life-support functions, such as cleansing, recycling, and renewal, and they confer many intangible aesthetic and cultural benefits as well".

In this view natural ecosystem services are those ecosystem *functions* that confer both tangible and intangible benefits to humans. While this definition seems to equate natural function with natural service, service is a *social concept,* based on the wants (usually recognized by society at large) and needs (often recognized only by a subset of specialists) of society. Ecosystem function, in contrast, is a service-neutral ecological concept. Based on the general acceptance of much human modification of ecosystems to serve humanity by totally replacing or enhancing preexisting natural functions, only a subset of natural functions *significantly* contributes to human service. By implication, a substantial fraction of the earth's natural ecosystem function was redundant and its service to humanity could be and was improved as revealed by a net gain in human welfare. Daily (1997) and Daily et al. (1997) emphasize, however, that as the impact of human kind on its environment has escalated, much more of the remaining natural function of ecosystems significantly contributes the remaining natural resources and services of substantial significance, and some significant contribution has already been lost.

Greater naturalness may, in itself, be the service of significance recognized not so much by the removal of human effects causing a deficiency of specific services, but by the removal of the effector (a dam, levee, channel, sea wall etc). This perception of naturalness does not require any past or present reference conditions to model in restoration process, it simply requires removing the effector. It is not an ecological concept (no vision of ecological change is involved), but rather a social concept of naturalness independent of response in the material world. The service value derives from the degree of dissatisfaction perceived in the edifice to be removed. The significant service is realized immediately upon removal of the effector (including any human evidence of the removal process itself). What comes of it in ecosystem function and structure is irrelevant. There are no material natural resources of significance from which the service originates and no service flow to resource utility. Because the service is not provided by the resulting material world there is little need for ecological/environmental methods and models to formulate for outputs and evaluate effects.

While this service may be socially significant, Corps policy seems to preclude its consideration. Corps policy is based in ecological concepts of naturalness, concepts based in the material world. Corps policy clearly indicates that the resource quality contributing to NER is to be determined through degraded ecological resources of social significance that respond positively to habitat restoration. Removal of perceived effectors is a restorative action, but not a vision of a restored condition. Although removal of human edifices, regardless of material outcome, may provide a valued service and a motivation for seeking Corps actions, the Corps determination of investment worthiness stems from the services conferred by specific manifestations of material resources. Whether and how the value of this non-utilitarian service can be judged, it would be judged incidental to the restoration of socially significant living resources. Any other non-utilitarian service not grounded in material ecosystem change would require similar consideration.

Conceivably, naturalness may be viewed as a collective material resource providing significant, but non-utilitarian service that results in intangible benefits. Different from value held in the removal of a human edifice, this recognition of significance in naturalness is held in specific manifestations of ecosystem structure and function. What comes of the edifice removal (or other alternative restorative action) is important result, not the edifice removal per se. This concept of naturalness is more likely to be based in indicators of reference-ecosystem resource condition. Any utilitarian concept of collective naturalness, such as for nature observation, is also based in specific manifestation of ecosystem function and structure. In other cases only a subset of significant services identifies the natural function and structure that comprise the underlying significant resources and naturalness is more of a means to an end than an end in itself. These services are most likely to be utilitarian, but non-utilitarian services are also conceivable.

Whether or not the social and ecological concepts of natural function are always or ever identical is uncertain and may be critical to realizing restoration objectives based on the material outputs amenable to scientific measure. The ecological concept of naturalness is based in scientific measure of human effect on the material condition of ecosystems, the same material conditions that comprise the resource structure and the functions underlying services. While the benefits to humans do not have to be based in material utility, either passive or active, ecological science is limited to the tangible world having physical existence, and how it responds to management. That is, ecological resources may provide services with intangible benefit, but they must somehow link back to tangible properties in the ecosystem if management for those properties, including restoration, is to *predictably result* in desired outputs. This section primarily addresses the ecological-evolutionary concepts of naturalness and resources.

The concept of natural integrity has emerged over the past two decade to ecologically characterize the naturalness of ecosystems.   Less known, but more relevant to the idea of humanity living harmoniously with nature are the concepts of *cultural integrity* and *ecosystem health*, which attempt to provide a theoretical basis for judging the appropriate mix of enhanced ecosystem service and natural ecosystem service. These concepts of natural and cultural integrity, and ecosystem health are closely related by concepts of resource and service *sustainability*. All of these concepts are addressed first in this section to establish a foundation for the following discussion of *ecological outputs* most appropriate for indicating *environmental benefits*.

3.2.1 Natural Ecosystem Resources and Services

3.2.1.1 Structure, Function and Dynamic Processes

Odum (1962) was the first to clearly describe the interdependent concepts of ecosystem structure and function, and later (Odum 1993) indicated that they formed the foundational resource for sustaining renewable natural resources. The general relationship among ecosystem structural and functional resources and natural services is represented in Figure 2.1 in Section 2. Parallel general examples of these relationships that might be associated with Corps restoration projects are provided in Table 3.1. Although they may appear straightforward, there is actually tremendous complexity in the linkages among ecosystem structure and functions that underlie services (Jorgensen and Muller, 2000). Ecologists have devoted substantial efforts to organize this complexity into manageable and holistic concepts of ecosystem structure (form) and function.

Definitions vary, but most agree that ecosystem function is what the community-habitat complex “does” when it is energized and structure is its material form. Function is process that predictably organizes materials into ecosystem structure, including physical features and species composition, relative abundance, and demographic attributes. Ecosystem function may be primarily physical, as it is in the hydrologic cycle, or primarily biological, as in the processes of population dispersal and ecosystem colonization. But in all cases both physical and biological form and process interact through the numerous links between habitat and inhabitants.

Ecosystem process is sometimes equated with ecosystem function. While all function is process, we separate function from other dynamic process. Ecosystem functions require driving forces that originate from the ecosystem environment, such as the energy in solar radiation, chemical reactions, gravity, and tidal effects. Most of the driving processes are dynamic (gravity being the major exception) and quite predictable at the source (the sun and moon, and the earth’s chemical composition and mass). However, random events also are dynamic processes that are not predictable for specific times and places and often influence driving forces through climatic and geological variation. Random events are far from irrelevant to ecosystem function, however, because they are common in ecosystems and interfere with the predictable organization of materials into ecosystem structure. Random events cause residual uncertainty in ecosystem output response to management or to natural events once the predictable relationships among ecosystem properties are understood. Many natural resource management actions have been put in place to ameliorate the effects of naturally random events such as flood, storm, and fire. But many other more subtle random processes influence the biological process of restorations as well, especially with respect to species recolonization of disturbed ecosystem sites.

Structure is the spatial arrangement of living and nonliving materials in an ecosystem at any one time and sequentially through time. The bio-structural components of ecosystems are created, maintained, linked, and destroyed through genetically coordinated function and function is maintained through structural dynamics. To refer to one implies the other. Physical mass and its instantaneous distribution in its various forms are measures of structure. For example, standing-crop biomass is one measure of ecosystem material form and biomass production is function. Similarly, stream discharge can be a function of ecosystems while water mass is its material form. Structure is sometimes referred to as the elements of ecosystems, especially in landscape ecology. As the term is used here, structure includes the arrangements of elements (individual organisms and other physical objects) in space.

Ecosystem structure, function, and dynamic process occur in all ecosystems regardless of how modified they may be by human actions. Whether or not structured or otherwise modified by humans, all ecosystems conform to fundamental laws of physics. A humanly engineered form of ecosystem structure functions to deliver the energy and materials needed by society according to the same natural laws that the sun delivers solar radiation to plant photosynthesis. All things human and nonhuman are natural in the context of natural "law" and neither good nor bad. Maximum human welfare, which is defined to be "good" or desirable, lies at that optimum condition somewhere along a gradient of human effect in a fully natural world. Thus the concept of natural function and structure as it has been defined in Corps policy—as occurring only in the absence of human effect—fits more comfortably into philosophical knowledge than scientific knowledge. What is most meaningful here for resource management is not whether human effects are natural, but what in ecological and evolutionary science is most meaningful for assessing human effects on ecological function and structure that somehow relate to the satisfaction of human wants.

Expression of ecosystem structure and function is often characterized by *diversity*, which is the variation in form and function that occurs in the genetic makeup of individuals and populations comprising a species, among aggregates of species within ecosystems, and in landscapes including numerous ecosystems. All diversity that is influenced by biological process in ecosystems has become known as *biological diversity*, or, more commonly, *biodiversity*. Landscape-level diversity is determined by the arrangements of different habitats and communities, including size, edge to area ratios, connectivity and patterns of habitat and community distributions with respect to other ecosystems in the landscape. Preserving genes, species, and even entire communities may be insufficient if *the landscape context* of community and habitat does not also provide the proper environment and supplies of energy and material for organizing life function and structure.

3.2.1.2 Roles of Genetic Information, Biodiversity and Species Composition

The expression of *genetic information* held in ecosystems is often identified as the most basic manifestation of ecosystem structure and function because it is the architect for other ecosystem structure and function at all hierarchical levels (Haywood 1995). The genetic information in ecosystems is most typically indicated in the biodiversity expressed in species and communities. Thus biodiversity indicators of genetic diversity and relative scarcity show potential as an indicator of environmental resource value once their expression is matched with indicators of human service.

Given the general ecosystem setting in which natural communities have evolved, genetic information generally determines the biomass and production of whole biotic communities through the collective function and structure of all species adapted to the ecosystems. Genetic information is transferred forward to successive generations of species populations making up the biotic communities of ecosystems. The functional and structural interactions within and among ecosystems start at the level of molecular events and work up through tissues, organisms, populations and communities interacting with their physical habitats. At the ecosystem level, the myriad miniscule structures and functions are "bundled" into conceptually more manageable aggregates such as emergent herbaceous vegetation, planktonic herbivores, primary production and carbon cycling.

Despite the complexity of ecosystems, the most commonly encountered measure of diversity is *species richness*—the number of species in a defined area—because it is relatively easy to measure. Also, species richness often correlates with more complex multi-criterion measures of diversity. The relationship between species richness and ecosystem functions, such as *primary production* (the first-level production most often associated with photosynthesis), has been a topic of active research in recent years. The results of this type of research are of exceptional interest to restoration practitioners because of the potential for species richness to serve as an indicator of functional status of ecosystems and, indirectly, as an indicator of ecosystem service.

The relative contribution of each species to structure and function is far from uniform, however, and simple biodiversity indexes can misrepresent exceptional contributions. Just as the different indicators of human physical condition are weighted according to their health implications (e.g., cancer verses acne), each species in a diversity index varies in its importance as an indicator of ecosystem condition. One shortcoming of a species richness index is its inability to discriminate the differences in dependency of ecosystem functions on single species and groups of species. Consistently rare species may invade and exit communities without much noticeable change in ecosystem function and structure. The comings and goings of rare species and their influences in the ecosystem may be below the limits of our ability to detect them in a sampling scheme, given technical and economic limits.

On the other hand, ecosystems can change dramatically when exceptionally influential dominant or keystone species come and go (Paine 1966, Power and Mills 1995).

Keystone species contribute disproportionately (with respect to their abundance) to both the functional and structural integrity of ecosystems, as do species that dominate because they are abundant. Except for keystone species, rare species contribute little to function but equally to simple measures of structural diversity. The potential roles of species richness, dominant species, and keystone species in development of decision-support tools are discussed later in Section 4.

The development of the ecosystem concept has emphasized structure and function, and their relationships. The structure theme typically has highlighted community diversity and composition (e.g., Pimm 1991). The function theme typically has emphasized energy flow through food webs, biomass production, and material flows and cycles (e.g. Odum 1984 , Ollinger et al. 1998, Bartell et al. 1999). Other theory has attempted to integrate the two themes through links between structural diversity and the stability of production and other functions (Pimm 1991, Holling 1996). Hannon (1973) developed the concept of structure through the food-web interdependence of species. He characterized community structure as a changing cross-section of community energy flow through food webs. Golly (2000) concluded that "ecosystem structure is the network of interactions between components of the system". Both structure and function contribute to the natural resources in ecosystems. Structure is the store of resource at any one time and function includes the production and decomposition resulting in the net store of natural resources.

3.2.1.3 Natural Service

Ecologists and economists have identified numerous examples of natural ecosystem service (e.g., Barbier et al, 1995, Daily 1997, Daily et al. 1997, Costanza et al. 1997, Table 3.1). The ecological view is consistent with the discussion of services in Section 2, but emphasizes more the connections between natural ecosystem service and ecosystem function and structure. In this regard, a helpful concept addresses the distinctions between the service recognized directly by the public at large and the service recognized indirectly through the specialized knowledge of ecosystem structure and function. When service is easily recognized, such as provision of watchable wildlife, ecologists are not needed to determine that a service indeed exists. On the other hand, when services are recognized only indirectly by ecologists working their way back from evident impacts on

Table 3.1. Generic examples of natural ecosystem structure, function, and service. They are associated to various degrees and form with river, coastal, floodplain and other ecosystems managed by the Corps.

ECOSYSTEM RESOURCES		ECOSYSTEM SERVICES
ECOSYSTEM STRUCTURE	ECOSYSTEM FUNCTIONS	
Carbon dioxide; biomass, water area	Thermodynamics; carbon cycle	Climate Regulation
Vegetation, floodplain & barrier islands	Wind, wave & flow alteration	Storm and flood Moderation
Lakes, ponds, aquifers, ice, biomass	Water retention and delivery	Water Supply
Particle size, root mass, debris dams	Soil and sediment movement	Control sedimentation
Biomass, sediment, humus,	Material trapping; decomposition	Contaminant removal
Species composition and diversity	Predation, disease, competition	Biological pest control
Biomass, air, water, species diversity	Plant and animal production	Food production
Wood, humus, clay, shell	Production of raw materials	Materials supply for commodities
Global species richness	Diversification and life support	Sustained genetic information
Water, wildlife composition, topography	Water flow; life process	Recreation/aesthetic
Landscape patterns of ecosystem form	Recovery after disturbance	More sustainable service

human welfare, then public policy needs to be informed about the connection. It is this scientific recognition of service that is most important to Daily (1997) and Daily et al (1997) to demonstrate—because it is not obvious.

Because ecologists deal with the tangible, material world, it is much less likely that ecologists will recognize an intangible human need. It is much more likely that they will reveal utilitarian services than non-utilitarian services. A good summary of a closely related concept can be found in Goulder and Kennedy (1997) in their utilitarian discussion of direct and indirect use of resources. While resources may not have to be used, either directly or indirectly, for services to be recognized by the public, ecologists are not likely to be able to help them out tracking back to ecosystem functions and structure if their is no connection through physical use, including any passive but satisfying sensual perception of the material world. Thus the environmental benefits that are addressed by ecologists are limited to benefits from utilitarian service.

Many uses of natural resources are direct and marketable; associated commercial and recreational services are priced, such as for the prices paid to gain access to and harvest timber and waterfowl from private wetlands. The price is paid because the service and its quality are readily perceived by the users. When natural resources are closely linked to a specific geographical area, that space can be valued indirectly through valuation of the functions (services) associated with direct use. For example, the indirect value of a forested wetland functions that generate timber supply (a recognized service) is relatively easily determined through lumber prices and harvest costs, which indirectly determine timber value, which, in turn, determines the wetland value for timber production (with additional knowledge about production rate and quality, and future demand for lumber). The property values for that specific service are readily determined based on projected logging income because the timber is literally rooted in the wetland and its production rate can be reliably calculated.

The value of other ecosystems contributing to resource harvest is obscured by incompletely defined ecosystem process and boundaries. Natural wetland support services for offshore commercial and sport fisheries production and harvest are much harder to value because services are dispersed and are difficult to tie to a specific area. Private property value associated with commercial fish production hardly exists outside fish-farm pens because most of the resources of value, the harvestable fish, disperse to public waters beyond the control of the property owner. While it is typically not feasible to trace the fish sold in individual economic transactions back to specific wetlands, it is feasible to estimate an average or aggregate service value for sustaining fisheries via backtracking through ecological food webs, fish migration pathways, and various material transport pathways to a general type of wetland condition.

As crude as this approach has been, this type of indirect valuation exercise, working back from direct service value to indirect service value through ecological pathways, has been used in part to justify public protection of coastal wetlands through state and federal permitting procedures. However, understanding of the natural ecosystem structure, function and other process linking to the priced resource is necessary before any estimate can be made of supporting ecosystem service value. There has been a long history of such analysis and decision in Federal and State waterfowl management, and to a lesser extent, other wildlife management. Starting in the 1930s, government wildlife agencies began to buy up lands to restore or create habitat for waterfowl using revenues from duck stamps bought by hunters. The buyers had to sort through land prices to determine the best buys based on the anticipated return in waterfowl-based benefits. Ecological methods were crude, but generally effective, long before models and computers allowed more sophisticated evaluation.

Restoring or setting aside existing habitat for an endangered species is also based on a scientific assessment of the ecosystem structure and functions required to sustain an endangered species. The habitat has no value, however, without the inhabitants. Thus habitat protection and or restoration have to be completely assessed ecologically, including all recovery pathways necessary, or the restoration could prove valueless for the intended purpose.

3.2.1.4 Relating Social Significance to Ecological Concepts

As outlined in Section 2, Corps regulations specify that restoration outputs should be characterized and evaluated in non-monetary metrics that are indicative of institutional, public or technical recognition of resource significance. Institutional indicators most obviously take form as environmental laws such as the Clean Water Act and Endangered Species Act, which emphasis recovery of and sustained maintenance of clean water and rare species. Both attributes of aquatic ecosystems are closely associated with the integrity of naturally functioning ecosystems. Public indicators of resource significance, led by the environmental NGOs, usually emphasize a sustainable ecosystem condition (increasingly referred to as ecosystem or environmental health) in support of human health, rare-species, recreational use, and other sustainable uses with mixed enhanced and natural services.

Technical assessments of significance have been captured comprehensively in statements such as the committee report of the Ecological Society of America about the scientific basis for management of the Earth's resources and maintenance of life-support systems

(Lubchenco et al. 1991). This professional society identified three particularly critical "problems facing humanity", including: "global change, maintenance of biological diversity, and the sustainability of natural and managed systems." These problems are linked to concerns of global proportion that may lead to resources of global significance.

In response to these problems, the Ecological Society of America has recommended major research initiatives to determine how *ecological complexity* controls global process change (including climate, patterns of land and water use, and environmental chemistry), how *biological diversity* (at genetic, species, and ecosystem levels) controls and responds to ecological process (such as energy and material flows through and between ecosystems), and how to restore and manage ecosystems to enhance *ecosystem sustainability.* The Ecological Society of America also has initiated integration of economic and ecological principles into a concept of natural ecosystem services, and extended the result to decision makers as an issues statement (Daily et al. 1997). The heavy emphasis of technical input on research needs reveals the uncertainty that exists with respect to how consistently the evolving principles and prevalent concepts about ecosystems apply to specific conditions.

Weaving throughout these institutional, public, and technical indicators of ecosystem resource significance is concern over how much alteration the *natural integrity* of world ecosystems can absorb before costly unsustainable states of desirable natural resource condition result. However, the concepts of natural integrity, ecosystem complexity, biodiversity, and sustainability have proven easier to address in the abstract than in practical application. The next subsection summarizes prevalent concepts pertaining to the natural integrity of ecosystems and how it relates to biodiversity and ecosystem sustainability.

3.2.2 Ecosystem Integrity

3.2.2.1 The Concept

Standing out categorically among ecosystem concepts of potential output importance is the *natural integrity* of functions and structures with respect to biodiversity maintenance, energy-flow, material-flow, and self-regulating sustainability. The concept of natural ecosystem integrity provides a theoretical basis for *measuring the naturalness* of ecosystems. The concept of natural ecosystem integrity has emerged most fully over the last two decades in response to management mandates, such as those included in the Clean Water Act, which seeks the restoration and maintenance of the physical, chemical, and biological integrity of the Nation's waters. In the narrow sense defined by Angermeir and Karr (1994), ecosystem integrity is the relative completeness of natural ecosystem function, structure, and associated complexity determined by ecosystem evolutionary history, which is reflected in the system's "ability to generate and maintain adaptive biotic elements through natural evolutionary process".

In the sense of the commonly accepted definition of Karr (1981,1991) and Angermeir and Karr (1994), natural integrity pertains only to the completeness of ecosystem structure and function within a specific ecosystem. In practice, natural ecosystem integrity is defined by reference to the state of existing unimpaired parts of ecosystems, and, much less commonly, by reference to a record of some previous more-natural state at the restoration site.

This concept of natural integrity is not universally accepted, however. Ecological progress in finding the "right" definition of ecological integrity has been slow according to others (Barkmann and Windhorst 2000). An important issue is the measurement of ecosystem integrity Ecosystem integrity has been measured using the component parts making up ecosystem structure (Karr 1993) and, less commonly, by using ecosystem functions (Schneider and Kay 1994). Whichever model/method is used, all measurement is based on sampling ecosystem attributes along a gradient of naturalness from most natural to most humanly modified.

A number of models of relative naturalness have been developed based on structural attributes including the Index of Biotic Integrity (IBI; Karr 1981, Karr et al. 1986), the Wildlife Community Habitat Evaluation (WCHE; Schroeder 1996a and b), and the Riverine Community Habitat Assessment and Restoration Concept (RCHARC; Nesler et al. 1995). The most widely known model addressing the naturalness of ecosystem function is the Hydrogeomorphic Approach (HGM; Smith et al. 1995). Other models can be calibrated for relative naturalness of both function and structure, including a number of process simulation models that have been developed. Section 4 discusses models in more detail.

Several general issues have been raised regarding measures of naturalness. Most have to do with the representativeness of sampled attributes and how they ought to be weighed in any single measure of natural integrity. The measures used in models are typically gross, rather than specific, based on aggregate indicators of structure and function and usually limited to one group of organisms (e.g., fish, benthic invertebrates, birds), which may or may not be indicative of all ecosystem naturalness. Although ideally based on a thorough sampling of relative naturalness and humanly impacted conditions over the entire ecosystem (e.g., warmwater prairie streams in agriculturally modified areas), complete characterization of the variation among samples along a gradient is difficult to do inclusively for the range of human impacts that can occur. The meaning of relative integrity becomes more vague and difficult to interpret in complex settings altered in many interactive ways by human impacts.

Another issue has to do with sorting the effects of natural stress from the effects of human-caused stress. Many natural stressors produce the same effects as anthropogenic stressors. Fire, flooding, drought, and other stresses can be traced back at least partially to human actions as well as to natural causes. The response of ecosystems to natural and human-caused stresses is difficult to differentiate. In the same ecosystem context, natural ecosystem restoration occurs at the same rate. Measures of natural integrity following severe natural stress and severe human-caused stress can have indistinguishable results. Differences become more recognizable as the frequency, duration, intensity and pattern of stresses begin to change because of human impact. Thus measures of natural integrity following a single event in an isolated location, whether natural or not, is of questionable utility as are measurements made without knowledge of previous natural and human-caused events.

Related to this is the concept of natural succession. Locally stressed ecosystems "restore" naturally through a series of overlapping but different seral stages, each of which is natural. Each requires its own reference condition to establish natural integrity. Successional ecology is increasingly finding considerable variation in how succession proceeds and how it finally manifests in a more-or-less stable structure and function. Any number of natural states can result, some of which may be misinterpreted as human effect.

Another related issue derives from the importance of ecosystem scale of effect, both temporal and spatial, and how that importance translates into meaningful assessment of ecosystem condition. A full description of ecosystem integrity would include all of the defining historic conditions and resulting functions and structure over the entire ecosystem. For practical reasons, variations from natural integrity have been measured over relatively short time frames and a limited fraction of the entire ecosystem. Thus the representativeness of fully natural conditions and variations from them is sometimes questioned, especially with respect to long-term temporal variation. Because ecosystem functions associated with natural succession often act over decades and centuries, a temporally inclusive concept of natural integrity is difficult to develop. Because sites within ecosystems can naturally assume any of a variety of structural expressions (e.g., Holling 1973, 1996), the characterization of naturalness based on a few local reference conditions can artificially narrow the field of possibilities at any point along the gradient of naturalness.

The relationships between structure and function often are assumed to be close enough to use measures based on structure as an indicator of total ecosystem condition at the time of assessment. While the relationships of structure and function are becoming better known in general (as discussed later in this section), relationships in specific settings are typically more uncertain. A common indicator of structural component integrity is the biodiversity indicated by native species richness, which frequently correlates with ecosystem functional rate in simplified experimental communities (e.g., Tilman 1997) and in variety of field studies (Schlapfer and Schmid 1991). This relationship between function and structure is critical to understand for restoration purposes, and is discussed in more detail later in this section. More complex measures of integrity are multivariate including, in addition to taxonomic richness, other measures of taxonomic and functional composition, abundance and organism health (Karr 1991).

The concept of natural integrity alone offers no easy way to judge the relative merits of restoring naturalness among different ecosystems. Two or more types of ecosystems with very different structural and functional attributes can have the same index of integrity, indicating that each has the same fraction of remaining natural integrity. An ecosystem with full integrity composed of a few common species has as much natural integrity as a fully integrated ecosystem composed of many rare species. Similarly, a highly productive ecosystem may exhibit the same fully natural integrity as one of low productivity. Thus, the concept of natural integrity provides little insight into the *ecosystem services* or benefits linked to proposed changes in the structure and function of those different ecosystems. *It is a service-neutral concept*.

Inasmuch as ecosystem restoration seeks to augment natural services, an index of natural integrity can be a useful metric for evaluating restoration investment decisions if the relative completeness of ecosystem structure and function is highly correlated with the quality and quantity of services provided. Because service provision and relative integrity are not necessarily closely correlated, however, restoration plans guided by an index of natural integrity would not necessarily provide for the sustenance of species that are vulnerable to extinction (sensitive, threatened and endangered), or other services of significance. One rough indicator of potential service value is the relative scarcity of the more natural ecosystem condition at a national level. Scarcity of function and structure may indicate scarcity of associated services. Yet the species of commercial, recreational, vulnerable species support and other service relevance typically differ greatly in kind and abundance in different types of ecosystems, and even in the same type of ecosystem located in different geographical areas. Certain types of wetlands, for example, have been judged to be threatened and growing more scarce at a national level while they remain abundant (some would say overly abundant) in certain regions, such as Alaska. Thus, the national scarcity of specific structural and functional attributes is generally more critical for evaluating and justifying ecosystem restoration projects.

3.2.2.2 Ecosystem Integrity, Sustainability and Scale

Odum (1993) suggested that the functional capacity of ecosystems to *sustain* diverse human services is the most fundamental natural resource requiring management stewardship. Diverse interpretations of the concept of ecosystem *sustainability* are encountered in policy such as that of the U. S. Forest Service management goal (Federal Register 2000) and national goals associated with economic development (e.g., The Presidents Council on Sustainable Development 1996; NRC 1999b*)*. Virtually all of these concepts either explicitly or implicitly link the sustainability of ecosystem function and structure to the reliability of natural resources and natural services.

At least two important concepts of ecosystem sustainability can be identified among such goals. Ecosystem sustainability is the maintenance of all natural parts and processes necessary for maintaining ecosystem integrity through a self-restorative process following local ecosystem disturbance. The *g*enetic information stored in species falls into this category because it provides the design guidance for restoring many of the natural parts and functions of ecosystems. An associated concept links the conservation of ecosystem functions with the capacity of ecosystems to accommodate environmental stress by transforming adaptively to other *self-regulating* states (Hollings 1973 and 1996). The variety of self-regulating adaptive states and the capacity to adapt are maintained as long as the genetic information controlling the process remains extant and accessible in species living within the ecosystem. The stress may be natural or, if human-caused, may be intentional (managed) or unintentional.

Ecosystem sustainability typically is described in terms of temporal dynamics, but is greatly influenced by the spatial scale of the dynamics and the pattern of the natural ecosystem expressions remaining during and following stressful disturbance. Local integrity in small fractions of ecosystems often varies naturally from ecosystem-wide integrity. Such local alterations occur naturally through climatic, disease and other natural stress, and are restored naturally through residual capacity for self-repair and, very importantly, through recolonization from unimpaired source areas. Natural loss and recovery of local integrity happens “routinely” when floods, fire and other extremes decimate only small portions of ecosystems. Immediately following a local flood event, for example, the species richness and integrity may be temporarily decimated while the remaining watershed system of similar streams changes little. The rate of recovery after stress removal usually increases as the intensity and size of the impacted area decrease and as the boundary between disturbed and undisturbed areas becomes more irregular.

Orientation and location of the locally disturbed fraction within the larger ecosystem also are important determinants of natural restoration rate and completeness. Especially influential are connecting vectors of wind, water, and other transport processes and the conditions of natural features connecting different ecosystem fragments. Disturbances at the edges of ecosystems tend to be less certain of full recovery and more likely to transform to adjacent ecosystem attributes than disturbances toward the centers of ecosystems. Even less certain is restoration of small and isolated patches of ecosystem far removed from other natural vestiges of ecosystems that have been largely converted to other structures and functions.

Natural integrity is permanently degraded once unique parts and processes are permanently lost, such as by species extinction. Otherwise, natural integrity is only locally altered to another state until that time when the stresses naturally wane or are eliminated through management and the naturally restorative process can proceed. Except for the intensity and duration of stress, which are typically increased by human action, many physical forms of human impact are difficult to differentiate from natural stresses (e.g., accidental fire, logging, flooding, lake formation, levee development, fire, invasion by new species). Other human impacts are globally pervasive, often systemic and more persistent, such as some chemical and climatic alterations. These are the most troublesome because they do not respond to localized restoration actions and may sometimes limit the effectiveness of restoring the most desirable ecosystem function and structure.

Human-caused stresses (e.g., dams, stream dredging and pollutants) also have locally transforming impacts, which, even after many years, can recover quickly to full natural integrity once the stresses are removed as long as enough natural ecosystem remains intact and well connected to the restored site. Certain stresses are more difficult to remove than others, however, such as refractory chemical or radiological contamination. Physical stresses typically can be eliminated more quickly. The potential rate of natural ecosystem restoration decreases as more of the natural structure and function is replaced with artificial features, function, and maintenance.

At some point, the combination of human and natural stresses accumulates enough to overwhelm natural recovery and the ecosystem-wide integrity and sustainability declines as unique parts and processes permanently disappear. While natural evolution of new genetic information tends to balance natural loss, exceptional human impact results in a net loss as extinction exceeds generation of new genetic information. This attrition of parts and processes limits the array of possible manifestations of ecosystem structure and function. From a management standpoint it becomes increasingly costly as it increasingly limits management choices.

Restoring the natural connections of degraded ecosystem areas to the largest remaining patches of natural ecosystem structure and function is an important key to management success in recovering threatened parts and processes to a sustainable state. Even when the past service conditions of degraded areas adjacent to natural areas with desirable natural services are less well documented than service conditions at sites far removed from the remaining natural ecosystem, the risks of recovering the desirable levels of natural services are likely to be lower at the adjacent sites where system connections are complete.

Whether ecosystem integrity or sustainability should be targeted for protection and restoration. Some natural resource managers prefer to emphasize ecosystem sustainability over ecosystem integrity because they believe integrity is less readily measured and evaluated than is sustainability (e.g., Link 2002). This preference depends somewhat on whether structure or function is more important to the manager. It also seems true that integrity is most often linked to structural attributes and sustainability is more likely to be linked to functional attributes, such as production. Link (2002) for example, noted that while ecosystem structure often changes locally those local areas of "ecosystems will continue to function, albeit at different configurations" of structure. An ecosystem area under the "stress" of resource use and management can result in a range of sustainable functional states depending on management objectives and system manageability. Typically, the structure of these different functional states are dominated quite predictably by relatively common plant and animal species. Sustaining specific compositions of scarce species in such locally managed area of ecosystems proves to be a more difficult thing to do, however. Reliable maintenance of rare species typically requires a larger scale of management consideration, including natural areas set aside from management. Despite the apparent differences, the concepts of integrity and sustainability are closely related and similarly depend on the spatial extent and patterns of ecosystem alteration by human activity.

The nearly universal manifestation of human impact among ecosystems may make measures of ecosystem sustainability more practical criteria for characterizing natural integrity than natural reference conditions. Fully natural conditions are increasingly difficult to find in many ecosystems. However, the choice of functional and structural indicators for judging sustainability is critical. If the emphasis is on sustaining all structure and function for future management options, sustainability ought to be gauged by the condition of the most vulnerable of irreplaceable parts and associated processes. Once extinct, these parts and processes compose the lost integrity of ecosystems.

The threat of permanent loss of ecosystem parts and processes often can be thwarted by management, but only if the status parts, processes and threatening conditions is tracked and conditions are restored at least to the minimum of ecosystem naturalness needed to assure sustainability. Examples of such tracking is the database, "NatureServe", which is maintained for state Natural Heritage programs and other users, and the listings of species status in the Endangered Species Act. These lists of vulnerable parts are among the clearest indicators of threatened natural integrity and sustainability of ecosystem attributes.

3.2.2.3 Ecosystem Integrity and Biodiversity

Some indicator of *native biodiversity* is the typical measure of ecosystem integrity. While native species richness is a common indicator of biodiversity, and sometimes is assumed to be synonymous, current concepts of biodiversity hold that it is more complex and comprehensive than species richness alone. This multidimensionality and comprehensiveness is revealed in the recent definition of Redford and Richter(1999): "*Biodiversity refers to the natural variety and variability among living organisms, the ecological complexes in which they naturally occur, and the ways in which they interact with each other and with the physical environment".* The definition used in Heywood (1995) adds nuance to this inclusive definition:

> "...biodiversity is defined as the total diversity and variability of living things and of the systems of which they are a part. This covers the range of variation in and variability among systems and organisms, at the bioregional, landscape, ecosystem and habitat levels, at the various organismal levels down to species, populations and individuals, and at the level of the population and genes. It also covers the complex sets of structural and functional relationships within and between these different levels of organization, including human action, and their origins and evolution in space and time."

All variation and variability in ecosystem the structure and function determined by life form and process is included in this comprehensive concept of biodiversity, which provides a theoretically complete measure for natural ecosystem integrity *and more*. Human alterations are also included in this broad definition, which is more consistent with the ecological concept of naturalness than with the social concept. Such comprehensive definitions of ecosystem biodiversity closely approach definition of all of the structure, function, and other processes composing ecosystem integrity, including human impact. But importantly, *biodiversity is more meaningful at a national level of ecosystem differentiation* because different ecosystems of the same integrity always have different expressions of biodiversity.

As inclusive as biodiversity is, it does not include those physical attributes of the ecosystem environment that are not a product of life processes. Where one ends and the other begins is difficult to determine, however. But the most physical of forces and constraints that fundamentally shape and drive ecosystems contribute to a larger ecosystem diversity, more inclusive than biodiversity. Such basic properties include the light entering the ecosystem, gravity, strong and weak forces in matter, the geological foundation, much of the topography, much of the hydrology, and some of the climatology. These are the physical inputs that are most fundamentally restored, if altered, to reestablish the natural ecosystem. Hydrology and topography are most emphasized by Corps restoration policy. Even these are influenced by life processes (through watershed and atmospheric processes) to an extent that may be difficult to assess, but is necessary for accurate forecasts of ecosystem response to management actions. Relevant to Corps restoration policy, biodiversity is an inclusive measure of those ecological resources that are a function of habitat restoration and the basis of gauging ecosystem restoration effectiveness.

When comparing ecosystems, biodiversity is a better indicator of self-regulating function, functional stability and sustainability of attributes than is natural integrity. Some ecosystems have lower biodiversity and functional stability than others of equal natural integrity. Ecosystems of low natural integrity are particularly vulnerable to great change when a new species invades them. A good example of the great change that can come about is the transformation undergone by lamprey and zebra mussel invasion in the Great Lakes ecosystems, which had relatively low natural biodiversity. Whether or not the lakes are becoming more functionally stable is yet to be determined, but probably depends on the extent to which native species are totally extirpated by the new species.

Biogeography in general reveals that many, if not most, species naturally invaded ecosystems in the past. Recent northward extensions of some species (e.g. the Virginia opossum and Cardinal) into different ecosystems is an example of a natural invasive process that is not necessarily destabilizing. Many past species invasions may have added to ecosystem biodiversity more or less immediately upon entry into the system while others may have decreased biodiversity, at least in the short run, by driving other species to extinction. However, Mora et al. (2003) maintain that the local fish species richness in many reef ecosystems is sustained by dispersal from biodiversity "hotspots" in the Indian and Pacific Oceans. This suggests a net stabilizing influence of natural invasion.

A number of species have been introduced in the U. S. for their recreational and commercial value, for example, without clear negative impact on global biodiversity (e.g. brown trout and ring-neck pheasant). Some of these species seem to have partially replaced native species contribution to ecosystem structure and function while increasing biodiversity and ecosystem service value. Also of interest is whether the means of invasion—by human vector or other means—makes a fundamental difference. This area of scientific questioning has definite implications for the concept of ecosystem naturalness and its measurement. Because biodiversity, sustainability of function and structure, and naturalness are often assumed to be closely correlated, these differences have restoration implications where the stated purpose is greater naturalness, as it is in Corps policy.

A simple species richness measure of either biodiversity or integrity is limited in scope and can miss important aspects of biodiversity, especially the physical variation in habitat, depending on how closely species richness correlates with other ecosystem variation and variability. Inclusion of habitat —the physical part of the ecosystem complex— and landscape —a mix of physical and biological elements— extends the concept of biodiversity well beyond a community measure and toward a more complete measure of ecosystem diversity most relevant for ecosystem restoration plan formulation and evaluation. Based on the definitions of Redford and Richter (1999) and Heywood (1995), virtually any change in the abiotic and biotic structure and function of a natural ecosystem would result in a biodiversity change, which might be measured to document when the variation inherent in an ecosystems natural integrity is surpassed and integrity is lost.

No existing quantitative measure of biodiversity has approached the system-wide inclusiveness of the Redford and Richter (1999) and the Heywood (1995) definitions, however. Most quantitative measures are indices based on the relationships existing between a relatively small selection of habitat attributes and certain biological attributes of ecosystems. The quantification may be as elemental as a species-area relationship (see Rosenzweig 1995), which generally demonstrates the relationship between the ecosystem area sampled and the number of species encountered. Numerous other ecosystem indices have been developed to include more community and habitat attributes and relationships, but relatively few have been applied beyond the site for which they were developed.

Where ecosystem feedback processes between community and habitat are essential to ecosystem characterization for plan formulation and evaluation, models that simulate the ecosystem state dynamics and incorporate the feedbacks may provide more insight for informed decision making. Dynamic state, process simulation models (e.g., DeAngelis et al. 1989, Bartell et al. 1999) also can be regarded as simulations of ecosystem biodiversity as defined broadly in Heywood (1995). In contrast to indices, they usually estimate how actual output concentrations, numbers, and other measures of populations, communities and abiotic processes might change, given changes in model-input conditions. But because of the complexity of real ecosystems, process simulation models, like all other models, cannot completely represent the diversification process in ecosystems and must rely on the capacity of aggregate biodiversity measures (such as functional guilds of species) to indicate habitat suitability for all species.

3.2.2.4 Ecosystem Integrity, Cultural Integrity, and Health

One difficulty encountered in the definition of natural ecosystem integrity is the growing scarcity of fully natural states. Studies in the most remote ecosystems indicate that few ecosystems are free of human influence and all within reach of civil works management have undergone some cultural modification. Numerous ecologists accept the impracticality of either protecting or restoring most ecosystems to fully natural states. They emphasize reference to a more natural state rather than to a fully natural state. Regier (1993) concluded that a practical “notion of ecosystem integrity is rooted in certain ecological concepts combined with certain sets of human values” resulting in a state of *cultural integrity*. Humanly modified ecosystems exhibit cultural integrity when they sustain a satisfying combination of natural services and artificially enhanced services both locally and globally. The idea that humanity can and should integrate smoothly into the natural workings of ecosystems is fundamental in the philosophy of environmental sustainability.

The Society For Ecological Restoration, for example, has defined restoration in terms of recovering and managing ecological integrity, including "sustainable cultural practices". Just as for natural integrity, the restoration of ecosystem integrity that includes sustainable cultural practices, or cultural integrity, would normally refer to historic description or existing reference conditions. Thus the concept of ecosystem cultural integrity is linked closely to the concept of human-welfare and environmental *sustainability* ("people on earth...meet their needs while nurturing and restoring the planet's life support systems"—NRC 1999b) and can have as much or more policy meaning with respect to cultural practice and resulting services as ecological meaning.

The concept of cultural integrity has much in common with the concept of *ecosystem health* (Costanza 1992). Both take much of their meaning from the sustainability of function and structure and the desirability of associated natural services. *A healthy ecosystem is one that is both sustainable and culturally desired*. Healthy states of cultural modification often are preferred over more natural states based on threats and opportunities associated with human health, property, and other sense of human prosperity. Therefore, a more natural ecosystem justifies restoration at a diminished site only when the perceived value of the restored services exceeds the benefits eliminated by the restoration.

Achieving cultural integrity and ecosystem health requires determination of the minimum spatial and other resource requirements preserving all relatively natural states in an ecosystem as it becomes culturally modified. In some cases, restoration will be required to assure continuity of relatively natural states. At some point, any further conversion of natural ecosystem process will threaten to compromise cultural integrity and ecosystem health. In those cases, commitment to maintenance of cultural integrity will require either cessation of cultural transformation or restoration of some parts and processes of natural ecosystems before other parts are culturally transformed. The underlying assumption is that functional and structural sustainability is possible in various states of cultural integrity as long as all of the ecosystem parts and processes remain available to convert to other ecosystem states when management objectives change. The *first rule for sustaining restoration options* is to maintain some minimum inventory of ecosystem parts, starting with species.

The most usual strategy used to restore cultural integrity and health *locally* is to improve habitat quality and connectivity within the physical limits of beneficial enhancements, such as improving clean water in modified waterways and harbors. This is most often achieved through structural engineering. In contrast, deficiencies in ecosystem integrity and health can be approached *globally* by restoring and sustaining the viability of all parts and processes contributing to natural integrity. This is most often achieved by removing the effects of past structural engineering.

3.2.2.5 Challenges to Managing For Natural Integrity

In principle, nothing short of maintaining a substantial fraction of ecosystems in a relatively natural state is necessary to assure that all parts and processes will be sustained. However, the precise fraction needed and its landscape position and integration usually are poorly defined and the methods for doing so continue to evolve rapidly. Restoring and protecting natural fragments of ecosystems large enough to sustain future management choice may require larger areas than first anticipated and active disconnection of the remaining native ecosystem from contaminated parts of the ecosystem. Changes that pervade and permeate throughout an ecosystem are among the major impediments to sustaining the fully natural state and are common threats to sustaining native biodiversity.

Potentially degrading pervasive changes include widely dispersed contaminants, global climate change, invasive nonnative species, and complete conversion of ecosystems to other physical forms. Contaminant removal can take decades following discontinued use of ecosystems for waste reception. Similar delayed responses can be expected for ecosystems that have undergone extensive physical transformation, such as changes in the flow, sediment loads and temperatures of natural river systems. While natural ecosystems can adapt to climate change along elevation and latitude gradients, the prerequisite space needs to be available. As has been mentioned, aggressively invasive species allowed access to ecosystems by human activity can cause large and permanent changes in the composition of ecosystems and significant changes in ecosystem function. Removal of invasive species often proves impractical once they become well established.

Thus, the most desirable combination of ecosystem services possible in ecosystem settings will rarely if ever occur in a fully natural ecosystem, even when the sole objective of management indicated by public consensus is to preserve or restore the most natural ecosystem possible for whatever array of services will result. The more practical restoration investment questions focus on determining how the extent recovery of a *more natural* ecosystem condition results in a more socially desirable mix of natural and enhanced services

3.2.3 Integrating Enhanced and Natural Services

3.2.3.1 In Search of the Ideal Result

The concept of sustainable development implies continued improvement of the human condition though seamless integration of natural and artificially enhanced resources for optimum delivery of services. A relevant project-planning question asks: What is the proper emphasis placed on artificial enhancement of certain ecosystem resources and provision for natural ecosystem resources to sustain the most beneficial combination of services? With respect to water-resource management, ecosystem restoration appears to be justified in those instances where previous artificial alteration of services has replaced natural services of greater social value.

Few would argue that artificial enhancement of specific ecosystem services entailing some *local* loss of ecosystem naturalness has not resulted in improved public welfare. Principles of water, forest, range, farmland, recreation-land, urban-land, fish, and wildlife management are based on the assumption that at least some artificial alteration of natural service is beneficial in the proper context, even when native biodiversity is locally depressed.

Few would argue, on the other hand, that what was thought to be enhancement of certain resources and services in fact ended up diminishing total benefit by unintentionally eliminating too much beneficial natural service. Correcting for greater benefit is merely costly when all of the parts and processes can be restored, but possible when justified based on the perceived benefits and costs. When parts and processes are entirely lost, complete restoration is impossible and no amount of corrective management can replace the lost management options

The Corps has received its environmental-improvement authority from Congress in recognition of correctable service deficiency and resource degradation. Much of the environmental legislation of recent decades is intended to reverse degradation of the general public welfare as a consequence of less than optimal management of natural resources and their use. Achieving this result requires identifying the desired mix of natural and artificially altered services and linking them back to the underlying resources.

3.2.3.2 Identifying The Desired Mix of Services

Artificial alteration of natural resources and services continues to enhance social benefits until the integrity of the natural system is so compromised that the sum of natural and enhanced service benefit begins to decrease (Figure 3.1). A general example is the accumulation of water-control structures for enhancing navigation and flood-damage reduction services that has contributed inadvertently to the growing scarcity of globally unique organisms. The exact relationships between natural and culturally enhanced services and their combined benefits vary from ecosystem to ecosystem and from one social context to another.

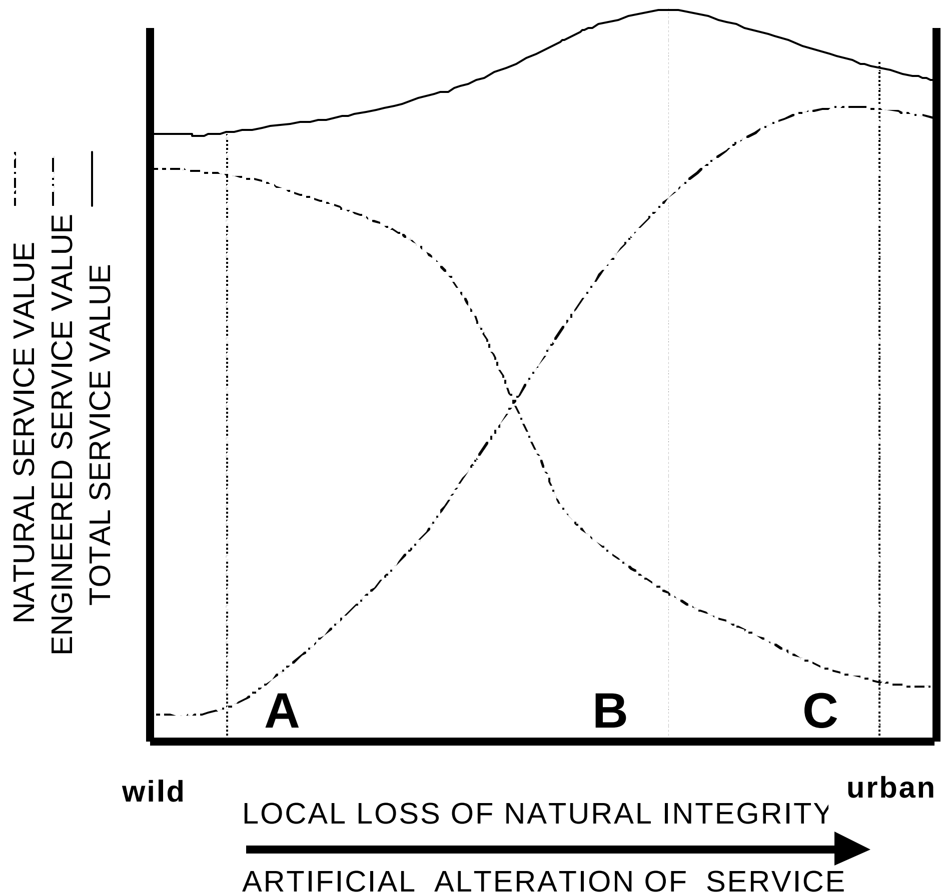

Figure 3.1. A conceptual example of value changes associated with natural service benefits and artificially enhanced service benefits along a spatial or temporal gradient from wild to highly urbanized condition. In this concept, all environmental and economic costs and gross benefits are assumed to be additive using some common unit of measure. At Point A on the gradient, the ecosystem is quite wild and most valued for its natural services. At point B, the combine natural and artificially enhanced service benefits are maximized . At point C, the ecosystem is artificially altered (urban development) to a point where most value is from development that has gone too far toward displacing natural services, resulting in decreased total benefit.

To illustrate the general point, three different ecosystem conditions are conceptually represented in Figure 3.1 at points A, B, and C along a gradient from fully natural ecosystem integrity through increasing degrees of cultural modification. As described by Regier (1993), each of these three states has come into an ecological equilibrium that sustains "an organizing, self-correcting capability to recover toward an end state that is normal...for that system." even though specific conditions at points B and C vary greatly from the most natural conditions at point A. These are all, therefore, sustainable states. At point B, the ecosystem is providing close to the mix of natural and enhanced services that provide maximum public benefit. At point C, the alteration of natural services has gone too far to provide the maximum benefit.

Transforming the concept presented in Figure 3.1 into practice is complicated because different services are not equally amenable to monetary valuation and summing monetary and non-monetary measures of benefit and cost has to be subjective. The inability to readily estimate economic values for certain natural services probably has contributed to a contemporary public sense that past water resources management has inadvertently degraded significant natural resources enough to warrant their recovery through restoration measures.

The Corps often is involved with some intermediate ecosystem condition broadly bracketing point B in Figure 3.1 where a more even mix of natural and artificially enhanced services are provided and where the combination of services at least in theory approaches maximum public benefit. These intermediate ecosystem conditions frequently have a more balanced mix of natural and artificially enhanced services than either the wilderness or the urban extremes, but not necessarily the optimum mix for maximum benefit. Further enhancement may be justified when the mix overemphasizes naturalness for the social wants and needs. Restoration may be justified when the mix overemphasizes enhanced services. A condition of overly enhanced services can result either because of past mistakes in judging the proper mix for maximum benefit, or because societal preferences have changed.

The past water resource engineering done to enhance services defined by authorized purposes (e.g., navigation, flood damage reduction, water supply, recreation) had to be economically valued in order to justify its construction in the first place. The preference for those enhanced services may have changed from the past, but can still be valued using the same techniques that justified the enhancement in the first place, as defined in Federal water resource management Policy (WRC 1983). At point C, where traditional water resources enhancement measures now dominate all service provision, most of the service has been and could now be economically valued according to national economic development criteria.

Where little service enhancement has occurred , as at A in Figure 3.1, much more of the ecosystem service is likely to be environmental than economic. However, some of the natural ecosystem output might be valued for its service much as it was for enhanced states. For example, natural rivers have navigation properties that can be valued just as culturally modified waterways are valued. Similarly the recreational service of natural rivers has been economically valued much as the recreation of reservoirs and waterways have been valued to evaluate their development. Some of the natural services of wetlands also have been monetarily valued as well (see Heimlich et al. 1998 for a review), albeit at different levels of confidence depending on the service and knowledge of natural function and structure. Other natural services have not been so confidently valued, such as the value of restoring natural ecosystem support of species vulnerable to extinction.

3.3 Ecosystem Outputs: Natural Resources In Support of Services

With respect to restoration *plan evaluation*, the ecosystem outputs of particular interest are the *significant natural resources* that both directly and indirectly underlie ecosystem services. The natural resources of concern in the Corps environmental policy have ecological attributes (WRC 1983). The concept of natural resources is as much social as it is ecological, being the “store” of materials and potential energy of immediate or possible use to humanity. Resources with ecological attributes fall into the general subcategory known as renewable resources, which are regenerated through *life processes.* In addition to living resources affected by life processes, renewable resources include numerous non-living products, such as the dead organic portion of soil and the water discharged from watershed influenced by life processes.

Traditional concepts of renewable natural resources focus on extractable resources such as the resources harvested in commercial fishing, duck hunting, timber, and livestock forage consumption. More contemporary concepts include nonconsumptive use, such as recreation based on observing nature or setting aside habitat use for endangered species. Underlying these resources, whether extracted or not, is a complex interactive network of nonrenewable and renewable structures and functions that provide for all of the energy and material needs of the used resources, including such basics as light, inorganic sediments and solutes, and water. This interactive complex of underlying natural resources comprise ecosystems that are indispensable for renewing the resources of direct utility and thereby take on significance and value indirectly through the used resources. While restoring a more natural state may include what is necessary to restore the meaningful, significant resources, it also may not when restoration is partial or if the history of the significant resources and the most natural condition is unclear.

This subsection summarizes some of the more important ecological concepts about how ecosystems work indirectly through function and structure to renew and sustain natural resources providing goods and services to humanity. Any attempt to rank the importance of the ecosystem outputs reflecting the functions, structure and sustainability of ecosystems immediately recalls the proverbial chicken and egg. Teasing apart ecosystem process risks loosing concept much as the forest gets lost from view as we focus on the trees and other parts. The order of discussion for topics in this section implies less about relative importance of ecosystem properties than it does the relative complexity and uncertainty of the principles. The four categories of structure and function used to develop this discussion start with energy flow and biomass production, followed by material flow and cycling, and hydrologic process, and culminating with self-regulation, functional stability and ecological sustainability. Each of the four categories of function and structure are compared to biodiversity measures for their potential utility as measures of ecosystem output for Corps restoration planning purposes.

3.3.1 Production, Biomass and Other Energy-Flow Outputs

3.3.1.1 The Relevance of Energy in Natural Structure and Function

All management of biological resources depends on natural *energy-process* dynamics to sustain renewable resource function and structure through the production and maintenance of community biomass (Figure 3.2). No other ecological output reveals more possibility for universal application than potential and kinetic energy in ecosystems. Energy is the one universally distributed natural resource found in all ecosystem form and process that can be compared as Joules or other unit of energy. However, like naturalness, *it provides little insight, beyond power supply*, into natural or management-enhanced *ecosystem service values.* Society examines relatively few services and their tradeoffs in terms of net energy gain and loss and, although a related concept of power maximization has been used to explore societal decision process (Odum 1971), the concept remains obscure and peripheral.

Because the diversity of natural resources associated with ecosystems appears to be important in determining the total service value of ecosystems, the processes by which community-level production is distributed among species groups, individual species and other resources are of great interest (Figure 3.2). While some natural resources are produced in large community aggregates of numerous species, such as the capacity of vegetation to store carbon and regulate greenhouse gas accumulation, most natural resources are uniquely linked to services provided by a small fraction of the ecosystem's species. For example, forests produce wood resources with a wide spectrum of uses, each tree species in the forest producing wood with a unique service quality. The raw energy value for fuel is only one source of value. Vertebrates provide recreation, but various species provide unique opportunities for recreation with different service values. Even endangered species are not treated as if they have identical value, some getting more protection investment than others. The diversity of services provided by an ecosystem contributes to how much they get used and how highly valued they are. That service diversity and value depends on the extent that production and biomass are partitioned into recognizably different species and other ecosystem forms and functions.

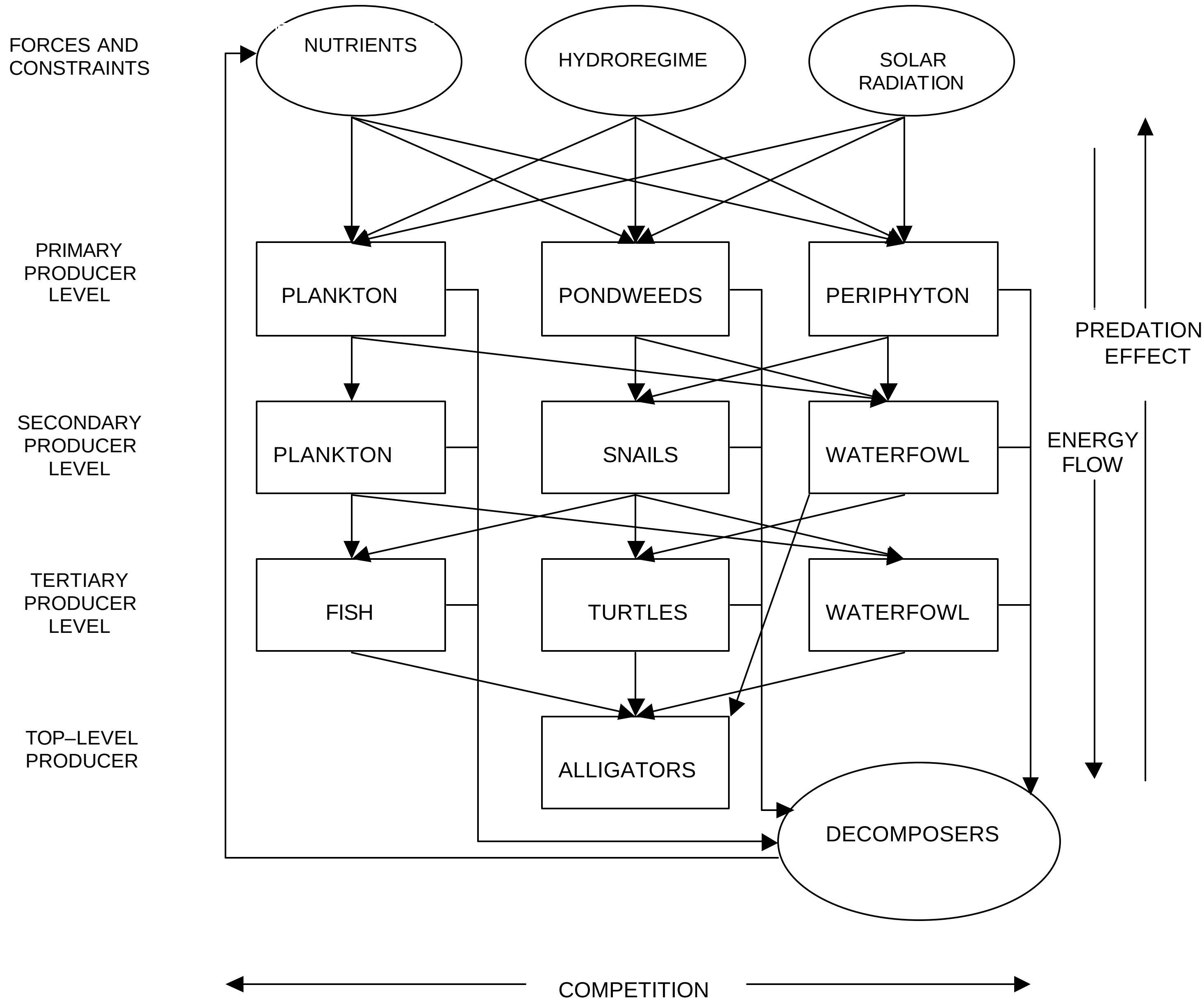

Figure 3.2. Community partitioning of energy and nutrient materials is determined by energy loss at each feeding (trophic) level, partitioning of resources among species in each trophic levels, and predation effects between trophic levels. Each level is occupied by many more species than indicated here by a few functional groups. In riverine and coastal systems environmental hydrodynamics influence resource partitioning at all points in the system.

3.3.1.2 Energy Transformation and Partitioning Into Resource Production

A basic natural limitation to the development of ecosystem biomass (potential energy) and biodiversity (diversity of potential energy forms) is the availability of energy that can be transformed into living process and transmitted from one living form to another through food webs. Any transformation of energy from one form to another via primary production and dependent food webs is accompanied by energy output in the form of heat. Ecological process is quite inefficient at transferring life-generating energy from one consumer trophic level to another. A large amount of energy is lost from the food web as heat with each transformation of energy from photosynthesis through subsequent food-web transformations. For this reason, food chains are of limited observable length, typically revealing only 4-5 energy transformations from primary producers to top carnivores (Pimm 1982).

3.3.1.3 Biodiversity and Production Relationships

The relationship between biodiversity, organic production, and service delivery is determined in part by the amount and reliability of energy available to primary producers, the energy loss in transformation, and the amount of resource partitioning among different life forms within each of the production levels. The complexity of resource partitioning, as indicated by species diversity, influences community persistence in the presence of destabilizing events and functional resilience following disturbance. Empirical tests support this theory more often than not (Tilman and Downing 1994; Naeem et al. 1994; Tilman 1997; Naeem 1998; Walker 1992, 1995, Schlapfer and Schmid 1991). Modeled relationships (e.g., Figure 3.3) are being refined and general concepts are gaining wider acceptance as they are tested with empirical data from other situations.

The insurance analogy, for example, is offered to explain how biodiversity increases stability of community production (Shigeo and Loreau 1999). Compared to a community with few species, a diverse community has a larger selection of adaptations to draw from as environment changes. While the relative production of species changes with changing environments, the total community production is sustained.

Tilman (1997) has provided both hypothetical models and empirical tests that indicate biodiversity is related to production and to resilience as measured by the recovery of productivity following drought disturbance. If native species richness proves to be a consistent predictor of functional performance in various ecosystems, it may serve as an index to natural service provision, such as sustained reproduction of genetic information and the reliability of an array of natural services aligned with ecosystem functions. Enough research has been done to recognize that numerous exceptions occur, although it is not always clear why. Schlapfer and Schmid (1999), in a comprehensive review of studies, show that positive relationships such as Tilman's (1997) occur much more often than negative relationships, but numerous other studies reveal no relationship. More research is needed to determine why the exceptions occur. Relatively little study has been conducted in freshwater.

The relationship shown in Figure 3.3 also indicates that, at any one time, *a small fraction of the species contribute to a large fraction of the productivity and to the resilience* as measured by return to previous productivity level. However, as climatic, hydrologic and other conditions in the ecosystem vary naturally the contribution of each species to total ecosystem function also shifts. Some common species become less common and some

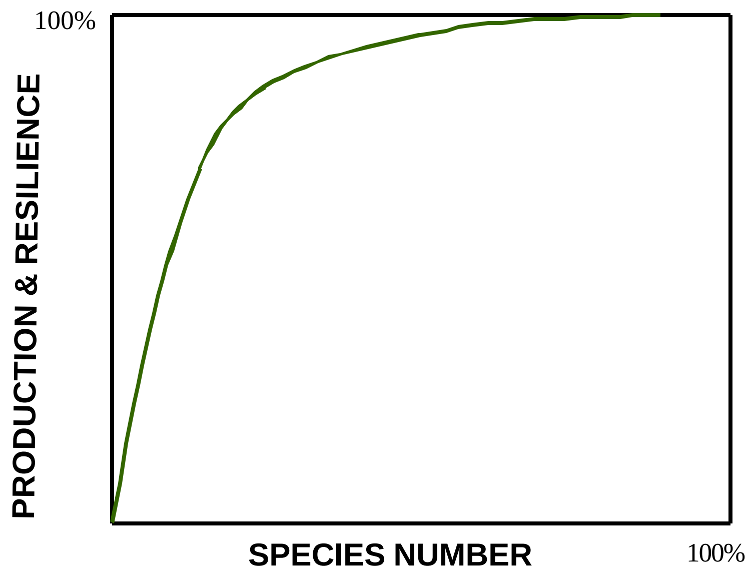

Figure 3.3. General relationships between a species richness measure of biodiversity and production and resilience functions in simple and complex systems (Based on information presented by Tilman 1997). Most ecosystem function is associated with common species. Most species ordinarily contribute much less to production-related functions.

rare species become more common until conditions change again. In this way, diversity sustains higher total production and more stable production and biomass. Predictable patterns of environmental variation maintain suitable conditions for all species some of the time. Each species has evolved means to persist through stressful periods. Nonnative, invasive species can play an important role because they are most likely to dominate production in a disturbed system and greatly displace the original diversity while restoring and sustaining production.

3.3.1.4 Relationships Between Biomass and Physical Process

Feedbacks between biomass generation and physical processes are common in ecosystems and cause physical inputs to change into significantly different output attributes, which often serve as the inputs to other ecosystems. For example, as biomass accumulates in watersheds the hydroregime outputs typically become more stable and substantially alter the physical input of water flow and amount into aquatic ecosystems. Aquatic species adapted to that hydroregime disappear quickly once the watershed is substantially disturbed by natural or cultural processes and the hydroregime becomes less stable. Another example of functional feedback control by accumulating biomass is the self-shading caused as photosynthetic biomass accumulates, limiting the rate of photosynthesis. Light is greatly reduced by terrestrial vegetation overhanging aquatic ecosystems or by algae within aquatic ecosystems, greatly reducing light input, altering light quality and influencing the amount and type of productivity in the underlying ecosystems.

3.3.1.5 Which Is The Better Measure of Integrity—Production or Biodiversity?

Is community production or biomass a more appropriate measure than biodiversity for formulating for ecosystem integrity and evaluating its restoration? As suggested by Figure 3.3, much community production and biomass is commonly associated with a small fraction of the species, some of which may be nonnative invasive species. Productive and abundant species often are less sensitive to habitat attributes than are those rare species that are valued most for their endangered status. The most productive species may not be indicative of the habitat needs of all community members, including the endangered species. Restoring community-level production based on the habitat needs of a few dominant species will not necessarily result in restoration of the rare species. In contrast, restoring ecosystem conditions, including removal of nonnative species, that will reestablish most of the native species richness, is more likely to restore community production close to the level of natural integrity. This is likely because the community members evolved with a set of native habitat and community features that determines the total production and it's partitioning among species.

3.3.2 Material Flow and Cycling Outputs

3.3.2.1 Material Types and Relevance

A close and necessary association exists among material flows, energy flows, production, consumption, and decomposition as schematically illustrated in Figure 3.2. Energy flow and resource partitioning drive material cycles and other material flows that have measurable ecosystem outputs in the form of material concentrations, densities, loads, transport rates, and dispersal rates. Materials include all matter organized into life forms, geological foundations, atmosphere, soils, and sediments and all matter in transport suspensions and solutions. Among the most prominent are nutrients required for life structure and function, inhibitory toxic materials, habitat substrate materials, and transport materials. Many ecologically active materials are transported by water, wind and other physical-transport materials connecting within and among ecosystems. Other important material-flows manifest in organism dispersal. How resource materials are distributed among diverse populations of living organisms determines the production and biomass of each population and the resulting biodiversity.

3.3.2.2 Nutrient Limitation and Materials Cycling

Where liquid water is plentiful, nutrients such as nitrogen, phosphorus and iron are commonly in least supply for the production demand and limit production rates. When habitat changes increase or decrease supplies of limiting nutrients, marked changes in community production typically result, accompanied by changes in ecosystem structure and function. Nutrients are cycled through ecosystems (Figure 3.2) as they are taken up in primary production and broken down by consumption and decomposition.

For nutrients with gaseous pathways—including carbon, hydrogen, oxygen and nitrogen— the scale of cycles typically are global in scope. Carbon dioxide released from one ecosystem conceivably can be taken up by ecosystems thousands of miles away. Sedimentary nutrients, such as phosphorus and iron, have no atmospheric pool and are typically cycled at smaller scales than nutrients having a gaseous cycle. They are more likely to be the nutrients limiting growth and production, and more likely to be cycled "tightly" within ecosystems, conserving them for future use.

Cycling efficiency is related to interactions between biomass elaboration and erosion forces operating in an ecosystem. Where erosion and transport forces are moderated by biomass type, amount, and distribution, as in a well-rooted forest or grassland, recycling efficiency is high. Where net erosion and transport forces are high, as on a well-watered steep gradient without much rooted biomass, recycling efficiency is low. Recycling efficiency is closely associated with the amount and distribution of biomass maintained in a system, which also is associated with biodiversity and productivity. Tilman (1997) discusses how, up to a point of greatly diminished returns, adding diversity to primary producers increases total productivity and the efficiency of nutrient uptake in plant tissues.

3.3.2.3 Ecosystem Boundaries, Interactions and Material Flows

Ecosystem boundaries are most typically defined by interruptions or abrupt changes in material flow rates and form. Watershed boundaries are among the most obvious for freshwater communities, but other topographic features and vegetation-defined boundaries most influence terrestrial communities. Yet, even in the most developed and clearly bounded ecosystems, material retention is rarely 100 percent. Ecosystem boundaries are naturally porous and the structure and functions of some ecosystems have evolved to depend on a reliable supply of materials "exported" from other ecosystems.

Thus, the rates, fluctuation, and extent of material flows among ecosystems greatly determine the interactions between habitat and communities within and across ecosystems. The nutritional outputs from one ecosystem usually are inputs required to sustain function in other ecosystems; thus, most ecosystems are linked closely with other ecosystems. Streams and lakes would be lifeless without wind- and gravity-driven loss of nutrients from watersheds, channels and basins. Similarly, deep lake and ocean bottoms would be lifeless if pelagic ecosystems were 100% efficient in recycling nutrients.

Because species diversity typically increases as the physical diversity of habitat increases (e.g. Rosenzweig 1995), the inefficiency of nutrient cycling probably has resulted in greater global biodiversity than if the ecosystems at the top end of gravity gradients were 100% efficient at retaining nutrients. Too much of a good thing also is problematic. The increased nutrient, sediment, and toxic-material loading resulting from watershed disturbances (e.g., crop culture, grazing) remains among the most pervasive of water quality problems complicating aquatic ecosystem restoration.

Even in the least disturbed states, small depressional aquatic ecosystems are naturally ephemeral, filling quickly with the materials exported from watersheds. Unique species diversity typically occurs in the oldest and largest lakes. Those communities adapted to small lakes and wetlands typically depend on creation of new habitats as old ones are eliminated.

3.3.2.4 Which Is The Better Integrity Measure—Material Flow or Diversity?

Is material flow and cycling associated with natural ecosystem integrity a more appropriate target for restoration than biodiversity? Determining what would serve as appropriate indicators of complex material flow processes is the first need. Biomass, production, and decomposition together provide a crude indication of the amount of material that might be taken up by, stored in, and released from an ecosystem. Because ecosystem biomass, like production, can be restored to a close approximation of original ecosystem biomass in relatively few species, either natural or exotic, the habitat and community needs of rare species containing unique genetic information could be easily overlooked. Less is known about decomposition, but some evidence suggests that a few dominant species can dominate this process as well. Past use of exotic plants to "restore" eroding banks and watershed often restored erosion rates to a close approximation of natural conditions, but not the habitat associated with the original plant species. Restoring the conditions necessary to reestablish the natural species richness, if not the entire original biodiversity, is more likely to restore structure and processes determining material flows and cycles than native biodiversity resulting from restoration of total ecosystem biomass, production, and decomposition.

3.3.3 Hydrologic Cycle Outputs

3.3.3.1 Water—A Material Of Exceptional Interest

Because water is a material of extraordinary functional importance in ecosystems and Corps resource management activities, it is treated here separately from other material flows and cycles. The behavior of water in that part of the hydrologic cycle influenced by living processes comprises a fundamental set of ecosystem functions (Muller and Windhorst 2000) of particular relevance for water resource management. Water is the universal solvent and the most important transport medium for nutrients, toxins, sediments and other materials. Watersheds are among the easiest ways to define ecosystem boundaries over a wide range of geographical scales and are the most practical means for monitoring and managing input-output dynamics of inland aquatic and estuarine ecosystems. Because the Corps manages surface water flow and storage, associated *hydrologic functions are among the most relevant to Corps-planned ecosystem restoration.*

3.3.3.2 Ecosystem Influences On Water Cycles

While hydrologic cycling mechanisms are predominantly physical and cycle fluctuations have profound impacts on life functions, life processes in the watershed also stabilize natural hydrologic fluctuation significantly. Many aquatic, wetland and riparian species are adapted to specific patterns of hydrologic variability. Through water dynamics, upland ecosystem functions influence the integrity of aquatic ecosystems. Natural communities generate surface roughness and organic soils with high capacity for retaining water and diverting surface flows into other locations, including subsurface ground waters. This in turn influences the efficiency with which essential nutrients are retained and cycled in vegetated terrestrial and wetland ecosystems, and kept out of aquatic ecosystems (e.g., Likens et al. 1977). Within aquatic ecosystems, the collective dynamics of water volume and flow are among the key physical variables contributing to the evolutionary history of inhabitant communities.

3.3.3.3 Corps Influence on Water

Civil works influence water and associated materials much more directly than ecosystem self-regulation and energy-flow functions. The Corps regulates surface water movement and shapes the form of surface water channels and basins. It indirectly affects the import and export of nutrients, toxic contaminants, and sediment, and determines the initial availability of these resources and inhibitory agents to ecosystem process. Without explicit linkage in restoration models, discovery of those links is left to the expertise of restoration planners.

One strength of the Corps with respect to restoration planning is its long history of hydrologic and hydraulic modeling, which can be useful in mathematically characterizing aquatic habitat. The Corps has much less experience either in modeling the effects of ecological process on watershed discharge of water into surface basins and channels (more the realm of the US Forest Service, Environmental Protection Agency, and Natural Resources Conservation Service) or in modeling the impact of aquatic habitat on community form and function (more the realm of the Fish and Wildlife Service and Environmental Protection Agency).

3.3.3.4 Which Is The Better Natural Integrity Measure—Hydroregime or Biodiversity?

Is the hydroregime associated with the natural ecosystem integrity a more appropriate target for restoration than biodiversity? Where hydroregime is the sole assortment of processes altered, it could be an effective indicator for ecosystem integrity once the relationship between ecosystem integrity and hydroregime is determined. But other, somewhat independent, factors often are involved such as changes in water chemistry and barriers to natural movements of keystone or dominant species. While variation in water volume, velocity, depth and width might be simulated at water control structures, uncorrected modifications can remain limiting in many situations (e.g. water temperature, nutrients, oxygen, turbidity, particulate and dissolved organic matter , bed load movement, physical barriers to organism movement).

In evaluating restoration plans, understanding of all of the significant ecological attributes interacting to determine the biodiversity is needed to assure restoration of some predetermined level of natural integrity. Restoration of all habitat and community conditions needed to reestablish biodiversity is a more reliable way to guide restoration of natural ecosystem integrity than restoration of select properties of habitats alone, even when those properties are exceptionally influential.

3.3.4 Sustainability, Self-regulation, and Functional Stability

3.3.4.1 Functional Stability and Resilience

Odum (1971) identified functional stability as the key attribute of natural ecosystems. Restoration of *self-regulation* generally results in greater *stability* of natural function and sustained provision of natural ecosystem service. Natural functions are the source of natural services, and are expressed in a wide variety of biological and physical outputs. But the self-regulation that results in functional stability is a biological master-function that determines the *sustainability* of all physical and biological outputs from ecosystems.

Ecosystem stability is often characterized by functional and structural resilience, which is defined in two different ways (Holling 1973, 1992, 1996, Gunderson et al. 2000). Most commonly, *resilience* is recognized as the capacity to reestablish a predisturbance equilibrium condition of structure and function following moderately stressful events. This form of resilience maintains and restores functional efficiency and is measured by *resistance* to disturbance and speed of return to equilibrium. This form of resilience usually results in a structural and functional recovery sequence (called ecological succession especially by plant ecologists) that is generally predictable in natural ecosystems in which a large reservoir of native species remain in the system and serve to recolonize stressed sites, once the stress is relieved.

Less commonly, resilience is recognized as the extent an ecosystem can withstand stress before changing to a different functional and structural state—that is, to another *stability regime*. This form of resilience maintains function at another level of efficiency and is measured by the magnitude of the destabilizing stress that “flips” some fraction of the ecosystem into another stability regime dominated by a substantially different biotic community and different habitat attributes. Destabilizing stress may take the form of either natural or human caused extremes, such as intense fire, flood, storm, drought, agricultural and urban conversion, and intense and pervasive pollution. The more persistent effects often act through altered soil and sediment structure, nutrient concentrations, and toxic contamination, and through the long-lived dominant species that reestablish following the stress. Destabilization is more likely to occur in pervasively modified ecosystems, in which the pattern, age structure, and other features of the dominant and keystone species have been substantially altered, thereby changing the species recolonization composition and sequence in the stressed site.

An example of functional efficiency maintenance is a river valley floodplain exposed to regularly encountered seasonal flooding. Floodplain species either continue to function, cease functioning but persist through the flooding, or are killed or driven from the floodplain. Recovery of function and equilibration following these "routine" events usually is rapid and generally predictable as locally extirpated species return to the floodplain from nearby refuges. As flood events become more extreme and far reaching, recovery following the event is prolonged, but given time, returns to the predisturbance equilibrium state as long as the sources of recolonization in the surrounding natural ecosystem generally remain intact (not fragmented). Great enough extremes in fragmented ecosystems, however, cause long lasting changes in the environmental forces and constraints operating in the floodplain and river habitat (e.g., all of the fine sediment and soil is eroded away leaving only large rock behind) and communities. Then the riverine ecosystem locally "flips" to another functional and structural state that is, for practical management purposes, permanent. This level of function can differ substantially from original rates and efficiency of energy and material transfer and conversion. Photosynthetic efficiency and plant production, for example, may decrease significantly in a river channel scoured of all its nourishing sediment and remain that way for a very long time even in an otherwise intact river ecosystem. Yet at least some production is sustained.

These different expressions of resilience have restoration implications. Restoration of self-regulating functions would be expected to restore resilience, greater functional stability and greater reliability of associated natural ecosystem services. When disturbance has resulted in a change within the same stability regime, restoration can work readily with natural resilience to restore the original equilibrium. These relatively predictable responses are most likely to occur in areas within and adjacent to naturally intact ecosystems.

As ecosystem conditions become more generally disturbed, however, the disturbance often increases the extremity and size of stressful events (e.g., flooding and drought in disturbed watersheds) and alters the recolonizing landscape. These changes in stress and landscape increase the probability of a flip to an alternative stability regime through processes that are not very well understood or predictable. Attempts at restoration may not be able achieve the original state of self-regulatory equilibrium and the result may exhibit structure and function quite different from the planning objectives. The probability of an alternative state establishing after the stress recedes increases as ecosystems become more fragmented and otherwise modified. This second, less traditional view of resilience may be the more relevant for managers attempting to deal with ecosystem restoration issues where cultural modification is extensive and intensive (Holling 1996). As Holling (1996) asks, "*If there is more than one objective function, where does the engineer search for optimal designs*?"

The outcomes of restoration actions in highly disturbed ecosystems are less likely than lightly disturbed sites to take the form and function of the original state and more likely to result in some "flipped" version of it. A flip of this sort in the restoration process should be of no consequence if greater naturalness alone is the restoration "design objective" representing the resource of significance. Each stability regime is an equally natural result of restored ecosystem function and structure. But if the specific resources and services are intended, such as particular rare parts and processes, this flip to a new regime may fail to carry the desired service with it. In addition, policy states that the restored condition should be more like the condition that would have occurred if no human impact had occurred in the first place. Regardless of the greater naturalness of the restored process, a new stability regime resulting from human disturbance in the influential landscape, may not satisfy this goal.

The scale of disturbance with respect to the ecosystem is a critical variable determining resilience. McNaughton (1977), for example, found that communities with the greatest production stability varied most in species composition adjusting to natural climate change. In adjusting, some species drop out locally while others with similar function replace them by colonizing from outside the disturbed ecosystem area. Functional stability is maintained at the local ecosystem level while component parts are maintained at a larger ecosystem scale.

It is therefore more consistent with theory and observation to expect species richness and other indicators of biodiversity to reestablish only approximately in a disturbed fraction of the ecosystem than to expect the same compositions. Specific compositions of rare species are especially prone to unpredictable restoration. Rare species not previously present may show up in place of the previous rare inhabitants. Especially when the services of rare species are of concern, the scale of ecosystem restoration planning needs to be adjusted to account for the dynamic between local disturbances and species resources in the influential landscape. In restoration actions, the risk of restoring at least some fraction of all significant rare species in an area of degraded ecosystem increases as the total number of significant species targeted for restoration increases.

Functional stability influences the reliability of various ecosystem services, such as the reliable supply and safe delivery of water for navigation and consumption, the production of raw-materials for commodities and recreational use, and the provision of suitable habitat for species vulnerable to extinction. Many of these services can be reestablished locally without the same species composition becoming established. This does not imply that restoration of functional stability will necessarily increase the value of an artificially enhanced service, although it might. An example would be watershed restoration above a flood-control impoundment resulting in decreased erosion that extends impoundment service life. More likely, the summed value of restored natural services may increase enough to warrant reduction of the artificial enhancement effects. For example, the removal of a dam and levees might result in more flow variation and flood threat while the restoration is justified by improved reliability of ground water quality, status of endangered species, and outdoor recreation.

3.3.4.2 The Source of Self-regulation and Stabilization: Genetic Information

Much of the important function and service associated with maintaining unique genetic information is linked with globally scarce species. In addition to potential resource-development value, those species provide functional "backup" that replaces common species when ecosystems undergo exceptional stress. Scarce species are not missed in most ecosystem functions under ordinary conditions, but are significant for sustaining natural ecosystem resilience and management options well into the future. The scarcest resources globally (e.g., species vulnerable to extinction) are among the most significant of those resources, and the most challenging to restore. Recovery of scarce species involves much greater uncertainty and risk than the restoration of common species and associated functions. This risk is often a reason given to avoid targeting scarce species, especially in small restoration projects, and instead emphasizing restoration of more common function and structure. (That rational of course misses the restoration point entirely). A fundamental way to control such risk is to scale up the recovery of ecosystem resources to a more inclusive level of influential landscape and community composition. Of course that is more expensive.

The most *critical function* for regulating and sustaining all ecosystem functions is the renewal of existing genetic information and generation of new genetic information. While there are abiotic self-regulating mechanisms that can act independently of biological process—such as the effect of humidity on evaporation or slope degradation on erosion rate—ecosystem resilience and self-regulation come from interactions of communities with their habitat and is imposed by inherited *genetic information*. Loss of genetic information reduces future resource development potential for various commodities, recreation, waste treatment, and other services.

Predicting exactly how much and what type of genetic information will result in significant resource change is impractical. Lacking that predictive knowledge, some benefit is derived from protecting all ecosystem processes that renew existing genetic information and generate new genetic information. Sustaining genetic information now at risk of extinction typically translates into policy associated with preventing species endangerment and recovering endangered species viability through natural ecosystem restoration. Sustaining the generation of genetic information requires maintenance of evolutionary context and process resulting in adaptive speciation at historic rates.

Adaptive speciation is a function that maintains all other life structure and function and *is among the least likely of functions to be artificially enhanced through engineered management.* While genetic traits of a few high-profile species can be maintained artificially in zoos or other means of last resort, it is generally accepted by conservation biologists that the variation and variability in natural ecosystem conditions that maintains adaptive speciation cannot be adequately simulated or enhanced on a comprehensive scale. At some point along a diminishing trend, the capacity for functional self-regulation and sustainability will diminish as species holding genetic information are lost at a faster rate than adaptive speciation replaces them.

The great concern existing among evolutionary ecologists and conservation biologists about decreasing global biodiversity (e.g. Wilson 1988, 1992; Heywood 1995) has loss of genetic information at its foundation. This loss has caused extensive reexamination of natural resource management actions. Native biodiversity has been eroded in numerous artificially-enhanced ecosystems (e.g. Stein et al 2000, Noss et al. 1995). Habitat degradation is the most frequently cited reason for loss of global and local biodiversity (e.g., Mac 1998). The ecosystem integrity required to sustain unique biodiversity has moved to the top of the list of management concerns (Schulze and Mooney 1993, Wilcove et al. 1998). Numerous U. S. freshwater ecosystems have undergone changes that threaten native biodiversity, but species in large rivers and isolated freshwater springs appear to be among the most threatened with total extinction.

The relative vulnerability of inhabitant species to extinction have been described for aquatic regions in the U. S. as delineated by watershed boundaries (e.g., Abell et al. 1998, Stein et al. 2000). Noss et al. (1995) have defined specific ecosystem types at risk of extinction. Such inventories typically include sensitive species not yet listed in addition to species officially listed under the Endangered Species Act. Definite "hotspots" of species vulnerability occur among aquatic regions. Scientific evidence indicates that recovering and sustaining vulnerable species involves preservation and restoration of ecosystems associated with those species. Mac et al. (1998) document the U. S. regional trends with respect to biodiversity and provide some insight into corrective actions.

Existing and future inventories of ecosystem vulnerability to species extinction may provide a basis for identifying restoration priorities. Perhaps as important, if management measures are successful in restoring the sensitive, threatened and endangered species collectively or even in part, most if not all of the physical, chemical and other biological attributes contributing to natural integrity would also be restored. Because management choices are limited by the loss of ecosystem components, reversing the trend of diminishing sensitive species and the fate of threatened and endangered species ought to be high on the list of restoration investment objectives.

As species become more rare, random events may play a greater role in determining the success of restoration. Therefore, those projects involving the greatest number of such species are more likely to succeed at some level because the risk of complete failure due to uncontrollable events in general decreases as more species are targeted in the planning objective. The relative risk is influenced by the degree to which the species are clumped within the same locations, vulnerable to the same threats, and affected by the same pathways and physical configurations of habitat.

The *best aggregate indicator* of the functional stability that sustains global biodiversity and other ecosystem services appears to be the native structural and functional biodiversity composing ecosystem integrity. If the relationships between habitat and community are indicated completely enough for habitat measures to restore the entire community, the native biodiversity indicator should also include the habitat needs of all of the globally rare species that form a subset of the local community biodiversity. No past measure of biodiversity has been totally complete across the spectrum of species and functions making up the biotic community. For practical reasons, they usually select for a taxonomic group (e.g., birds, fish) or a group occupying some fraction of the physical space (e.g., plankton, benthos).

The likelihood that an index of biodiversity will be inclusive of all significant functions and structures in ecosystems will increase with the comprehensiveness of the biodiversity measure and the links to habitat attributes. While species richness is commonly encountered in biodiversity indices, it is typically limited to a single taxonomic category such as fish and large aquatic invertebrates. Indices also are limited to the sampling framework used. For example, sampling fish or plankton in the water column may reveal little about the state of the stream or lake bottom. Indices often are time sensitive as well because species and other ecosystem features commonly change locations, form, and activity as seasonal changes occur. Because of these limitations, many indicators of biodiversity are functionally and structurally selective and likely to incompletely indicate the desired level of naturalness. *Care must be taken to assure that the measures of biodiversity, captured in relationships between and within habitat and community, are inclusive of the resources of significance.*

3.3.4.3 Habitat, Diversity, and Functional Stability

Decreased biodiversity often is associated with destabilization of ecosystem function and dependent natural services. Recent experiments confirm that biodiversity enhances reliability of function in a variety of ecosystem conditions (e.g., Naeem and Li 1997, Tilden 1997). The condition of the physical environment contributes to the maintenance of diversity, diversification, and functional integrity. Just as true, however, the condition of the biotic community, including its diversity, contributes to the development and maintenance of habitat for each species and for the entire community.

Because habitat and community evolve together into a functional whole, ecosystem restoration cannot be fully captured in an abiotic concept of habitat. Precisely predictive indices usually need to include elements about biological conditions in the influential environment of the restoration project. The location and connectedness of the project in the larger context of the landscape holding the source of community restoration components is pivotal in determining restoration success or failure.

Restoration models typically need to account for measures that restore the balance between *local* species *extinction* and *re-colonization* from other locations in the ecosystem. A model that links active habitat restoration measures to a passive and natural biodiversity restoration process typically will need to include landscape features that indicate habitat connection quality to colonization sources. This lack of attention to such connections is a leading cause for failure in restoring targeted species of significance in past restoration projects. Even in the best restoration efforts, attention is often too focused on restoring the hydrology and channel/basin geomorphology in a relative small segment of ecosystems. Corps policy tends to reinforce this focus. The habitat ends up being restored as an isolated island disconnected from the influential ecosystem in critical ways. With incomplete routes for re-colonization, the community fails re-colonize or to be sustained by the continuous movement of organisms and life-support materials between different areas of the ecosystem.

Restoring the needs for sustaining species vulnerable to extinction extends beyond physical habitat to the entire community-habitat complex because living organisms contribute to the habitat of other species and self-regulating mechanisms are associated with community diversity. To be effective, ecosystem restoration approached through habitat measures must carefully consider the restoration of community-habitat partnerships required to accomplish the justifying objectives. Restoration of physical habitat is inadequate for recovering genetic information held in endangered species without assurance that previous predator-prey and other community interactions will be restored as well.

Examples abound of species endangered in part because a non-native predator or competitor invades the system, or a species they depend on disappears. Invasive species, such as lampreys, combined with other factors probably played a role in the extinction of a white fish species in the Great Lakes following lock and dam construction (Smith 1972). The freshwater mussels that have undergone extensive endangerment and extinction in southeastern rivers usually require a unique fish-species host for the larval stage to survive and local elimination of that species probably has contributed to mussel losses (Williams et al. 1993).

3.3.4.4.Resilience, Stability States, and Natural Ecosystem Integrity

Holling (1973, 1992, 1996) has observed that ecosystems respond to stress by shifting to a different level of integrity and functional stability once the resiliency of a particular functional state is exceeded. One variation of this concept is illustrated with a simple model in Figure 3.3. As long as environmental stress does not exceed resilience, an ecosystem will generally recover the preexisting state of equilibrium once stress is relieved. The process depends on population re-colonization from within and outside the disturbed area and natural community succession. For some ecosystems, resilience may act over decades to centuries following extreme stress.

Ecological theory contends that a naturally integrated state occurs over a range of structural and functional conditions reflecting the variation associated with ecosystem instability (Holling 1973, 1996). In any one state, some mean condition also exists short of the maximum integrity for that state. For example, as illustrated in Figure 3.4, a species richness index of 100 might be identified in a sequence of such determinations with an index range of 90 to 100 and a mean of 95. A corresponding change in functional rates may also occur, but probably not in direct proportion to changes in species richness (this is important point is discussed in detail in a later subsection).

With stress, local parts of natural ecosystems often shift from one state to another structural state while sustaining similar functionality after some species locally die out. Production and materials cycling are sustained even though certain species are locally extirpated (but not globally extirpated). The main functional and natural service difference that might be identified would be associated with the local loss of sensitive species. With extreme stress, the composition and the function can change dramatically to a new equilibrium condition, new level of resiliency, and a somewhat different measure of functional and structural integrity. This new ecosystem state might exhibit *cultural integrity* or *ecosystem health*, however, in the sense that the community maintains coherent function around an equilibrium established under new environmental constraints, if a desired mix of artificially enhanced and natural services results (Regier 1993, Costanza 1992).

Even though many of the ecosystem services associated with the natural ecosystem integrity may be diminished from this new ecosystem state, the level of cultural integrity can be sustained indefinitely with certain conditions being met. Those conditions include continued exclusion of some species and functions from the original ecosystem

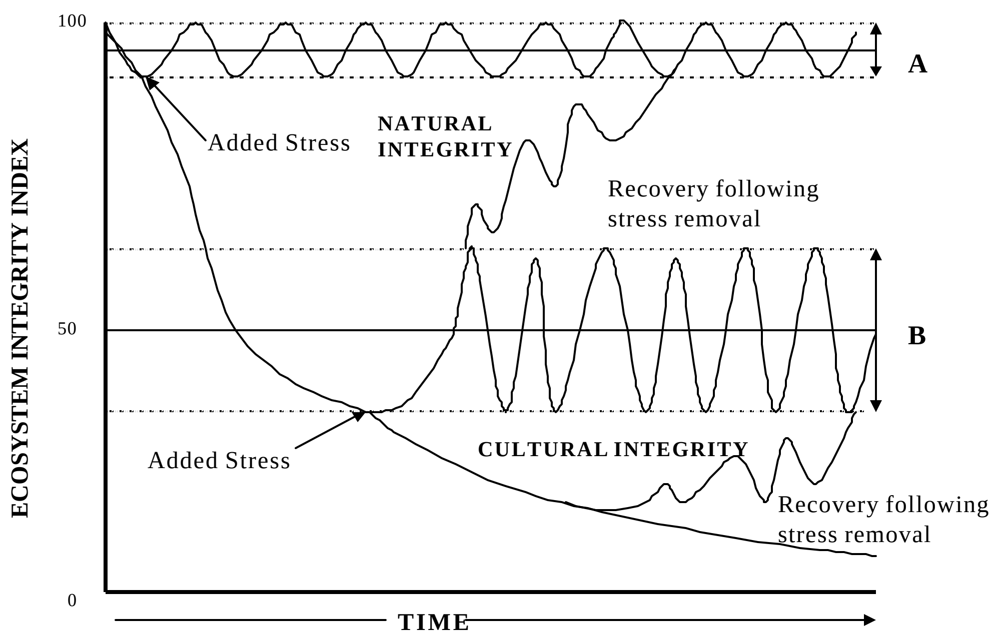

Figure 3.4 The concepts of natural (A) and cultural (B) integrity at a local site in a river, wetland or other ecosystem. Both natural and culturally modified sites show long-term functional stability and sustainability. Stressors can be natural (usually temporary) or cultural (often sustained) but full recovery can occur from either source of stress, once removed, if enough of the natural ecosystem remains intact .

composition maintenance of enough of the fully natural ecosystem to sustain all ecosystem parts and process beyond reach of the cultural stress. Despite local loss of integrity, this new state is self-regulating and self-sustaining, both locally and throughout the ecosystem, until environmental changes allow recovery or force a shift to another composition and level of functional stability in the stressed area. In this new state, the species richness index might average 35 and range between 20 and 50.

Evidence of change includes a different species composition, species diversity, functional rates, and variation around mean output amounts of ecological resources. Local ecosystem changes of this intensity and consistency are typical of extreme cultural influence. Examples include city harbors and riverine waterways where physical, chemical and biological change have a concentrated but local effect on otherwise natural ecosystems.

3.3.4.5 Resilience, Cultural Ecosystem Integrity, and Sustainability

Greater uncertainty in ecosystem condition following stress is introduced more or less in proportion to human impact in the influential ecosystem. Depending on the degree of stress, the structure and function of the ecosystem may change dramatically (flip to another stability regime), but may reach a new level of functional and compositional stability. As demonstrated in Figure 3.4, the species richness index might average only 35 and range between 20 and 50 in this new state (a species richness or other measure of ecosystem integrity could be readily converted to an index varying from 0 to 1.0 or other arbitrarily chosen range). Evidence of change includes a different species composition, total diversity, functional rates, and variation. Often in such settings, the more widely distributed species with wide tolerance to environmental conditions remain after elimination of the narrowly adapted species with more localized distributions.

Where human impacts are maintained locally the associated stress also is sustained, preventing recovery to the more natural conditions of the adjacent ecosystem. Aquatic ecosystems continuously stressed by water pollution usually reveal cultural change to a simpler structure often characterized by lower species richness and a greater functional and structural instability, such as the algal "blooms" and die-offs associated with excessive nutrient loading (cultural eutrophication). Under those circumstances the resulting oxygen depletion can cause a shift to a much simpler consumer diversity and greater reliance on microbial function accompanied by more variable community production and biomass. However, even these greatly simplified communities can persist through time, albeit with greater functional variation and less consistent delivery of natural services. They also can be restored to a condition quite similar to the natural integrity revealed in undisturbed aquatic ecosystems as long as the necessary connections are made between restored site and natural reservoirs of integrity.

Permanent structural changes that limit water-level fluctuations and eliminate biologically important connections with peripheral stream and wetland habitats often result in greater physical stability but reduced native biodiversity. Species are locally extirpated when the habitat connections and variability they require are eliminated.

However, the resulting communities also can be self-regulating and self-sustaining as long as stress, habitat fragmentation and other controlling factors including management measures remain effective. Depending on the species that are locally extirpated, the stability of at least some community functions may actually increase, such as may occur when ecologically influential migratory species are excluded from ecosystems.

If self-regulation and sustainability of function were the sole measure of *ecosystem health* many ecosystem conditions would qualify as healthy while exhibiting undesirable traits. The "open sewers" of the past exhibited community self-regulation and stability, but were esthetically displeasing and sometimes threatened human health. Even ecosystems exhibiting full integrity were often undesirable because of various perceived shortcomings resulting in corrective actions to protect human health and property and to enhance commerce and other beneficial activity.

Thus, the concept of ecosystem health is service-oriented as well as culturally sustainable. As defined by Costanza (1992), ecosystems are healthy not only when they are self-regulating but also when they produce a desirable array of natural and enhanced ecosystem services. The concept of ecosystem health marries social and ecological measures of ecosystem condition. In addition to self-regulation, a healthy ecosystem must provide a desirable mix of natural and artificially enhanced services that results in sustained level of human welfare. Neither maximum ecosystem health nor cultural integrity exists if the array of provided services is not what is desired or the system behaves chaotically.

The high probability that a number of different sustainable natural states and sustainable cultural states can exist simultaneously within a single ecosystem's geographical area indicates that sustainability of ecological structure and function is not in itself a very precise way to discriminate the relative desirability of the various states. Desired levels of service and maintenance costs are likely to differ depending on the ecological conditions and the social setting. The healthiest state is the alternative that appears among stakeholders to generate the greatest total sustained net benefit. However, social demographics and preferences may shift quickly in ways that are not easy to forecast, requiring consideration of new management measures once the expressed needs of society change. Thus, *sustaining the management-measure options* for shifting to a healthier state in response to social preference changes *requires maintenance of all of the necessary ecosystem parts and processes.*

Assurance that all of the ecosystem parts are made secure through preserving some part of the ecosystem is a fundamental priority in maintaining planning flexibility. That there is significance in this pursuit is indicated by social commitment required to maintain habitat quality critical to the viability of all rare and unique species under federal law. Ecosystem restoration is most justified, it seems, where past management decisions have compromised critical habitat and the investment risks associated with its restoration are judged acceptable. The least risk of restoration failure would most typically be associated with those ecosystems supporting the greatest number of vulnerable, globally unique species where cultural modification is not extensive and restored habitat is closely connected to existing refuges for vulnerable species.

Restoration for recovery and maintenance of vulnerable, globally unique species becomes less tenable as the degree and complexity of cultural modification increases and as the distance to natural ecosystem conditions increases. The Clean Water Act accomplished much in the way of partially restoring many of waterways, but relatively few have been fully restored and some may not be fully restorable because they have "flipped" into a state that is either technically or socially irreversible, they have already lost species to extinction, or they exist in a landscape context that is likely to replace the existing state with yet another stability regime different from the desired state. In carrying out the Clean Water Act, state and Federal agencies agreed to what amounts to levels of cultural integrity indicated by different water quality standards for different assigned uses, ranging from the most lightly used natural states to intensively used and highly modified states in urban settings. Standards for the intensively used systems may result in ecosystem conditions that "look and smell" more or less "clean" and provide some recreational fishing and bird watching, yet remain highly modified and not suitable for recovery of species vulnerable to extinction

Justification of ecosystem restoration in highly modified ecosystems might be contemplated based on the anticipated recovery of unknown levels of natural services. This justification would derive from the assumption that biodiversity indicates greater stability of ecosystem function and greater reliability of natural service delivery. However, ignorance of ecosystem relationships is just as dubious a justification for possible restoration of more reliable service provision as it would be for restoration of a floodplain for possible reduction of downstream flood damage. Biodiversity metrics alone, or any other indicator of relative naturalness and/or functional stability, do not indicate where a condition of cultural ecosystem integrity might exist or what levels of functional stability occur without prior calibration of the relationship between ecosystem biodiversity and the average amount and reliability of service provision. The biodiversities of those different states of cultural integrity cannot be predicted without prior measure of the conditions determining both the stable states and their associated biodiversities.

Understanding of the links between habitat and community in ecosystems, and to resource outputs that provide natural services, is key to restoration success. Those links determine the necessary management measures and their investment justification. The relationships and interactions need to be determined and quantified if ecosystem restoration decisions are to effectively restore a more natural state with the anticipated resources of significance. Models that define relationships between habitat and an inclusive measure of biodiversity ought to useful for environmental benefits evaluation, but only when the connection between biodiversity and societal demand for natural service are established. Under existing Corps policy, the services that most clearly appear to qualify for objective formulation for ecosystem restoration are those associated with securing resource options for the future. Biodiversity-habitat and ecosystem models may serve to guide plan formulation to attain greater naturalness once assured that the model captures all of the conditions necessary for securing the significant resource options. When specific resources are targeted, however, a biodiversity model will not indicate the significance of plan effect without prior calibration of the relationship.

3.3.5 Biodiversity: The Most Inclusive Output Indicator of Naturalness

If any result standouts from this discussion, it is the complexity that exists in the relationships among structures and functions comprising the interactive complex of habitat and community that define the naturalness of ecosystems once each state of naturalness is fully described along scales of human effect. As conceptualized in contemporary ecological thought, biodiversity is the most inclusive output measure of complexity in natural and humanly modified ecosystems. Measures of ecosystem naturalness in ecological output response to natural process and management measures can be indicated by holistic measures of community production and biomass, ecosystem materials retention and export, water discharge dynamics and amount, and stabilizing functions associated with resilience, and/or biodiversity. Some functional outputs are most evident in natural community process, such as biomass production and population dispersal. Other functional outputs are associated more with the physical habitat, such as watershed discharge of water and transported materials. All are interrelated sets of functions and structures that often link directly or indirectly to biodiversity as measured in studies of natural or human-caused variation in habitat and community expression.

Ecosystems are too complex to adequately characterize for restoration purposes without multi-metric habitat-community models. The most inclusive concepts of biodiversity extend beyond the community into the physical habitat (Heywood 1995). Simple biodiversity measures, such as a species richness-area relationship (Rosenzweig 1997), offer little for assessing the total ecosystem condition without more explicit links to the qualities of habitat and community conditions. The more inclusive measures are more likely to be multi-criteria indicators incorporating both habitat and community properties. Measures such as IBI may qualify, but only after the community outputs making up the index are thoroughly linked through cause-and-effect relationships to community-habitat variables.

As determined above, while biodiversity as it is measured now is the most inclusive indicator of biological naturalness, it is not a totally inclusive measure. Even if that were not the case, the biodiversity of natural integrity does not seem to hold up to the need for a national-level of “standard-unit” measure. Whereas the biodiversity existing locally in an ecosystem can be gauged against fully natural sites within an ecosystem, there is no logical way to compare across ecosystems nationally. Two ecosystems of equal integrity can have very different biodiversities. It is also difficult to determine what increments of biodiversity mean in terms of their relative naturalness, especially when the service value perceived is intangible.

3.3.6 Ecosystem Outputs Other Than Biodiversity Outputs

All of the above ecosystem output categories have centered on the relationships between habitat and the inhabiting community. The use of habitat-based methods has been in particular criticized for the likelihood of their not being inclusive enough of all Federal interests associated with a restored condition (NRC 1999a). Community-based habitat units as indicated by a comprehensive definition of biodiversity are more likely to be inclusive of all renewable resources that are the product of ecological process. Community-habitat measures may also be complete enough indicators of a more natural state to actually restore physical features and outputs underlying certain services (e.g., water supply, treatment, and regulation). Even so, a biodiversity indicator will not provide explicit measure of important outputs, such as water discharge, quality, and flow changes caused by life processes. Although such methods might formulate for the more natural status of these outputs, they provide no quantitative information useful for indicating relative or absolute value. In such situations multiple measures are required when they are relevant to the decision process.

For example, in addition to supporting living plants, animals and microbes through habitat functions, wetland functions influenced by life processes include groundwater flux (recharge and discharge), wave and current energy dissipation, surface and subsurface water storage, and nutrient and other materials sequestration and release. These functions are not necessarily restored independently of life functions, but the output measure that needs to be known to evaluate the resource significance is not captured in a biodiversity measure. These need to be considered in addition to community biodiversity for thorough evaluation of all effects. Ecosystem function indices such as those described by Smith (1995) are able to address the relative quantities of biodiversity and various other outputs (e.g., water discharge, nutrient retention) independent of biodiversity.

Existing measures of biodiversity now fall short of representing the nuances of natural conditions accurately and uncertainty caused by random events limits the precision of measurement. This is true for both specific biological resources of significance, such as rare species and physical outputs. While the relatively common biodiversity included in most existing models may be accurately foretold by habitat restoration, the forecast recovery of biodiversity may not include recovery of specific resources. Even if a complete understanding exists of interactions among habitat, communities, and all specific outputs from ecosystems, many of the natural processes influencing human services will remain uncertain because of random events. Thus planning needs to consider the risks of not realizing significant enough response based on averages.

3.3.7 Relationship of Significant Resources to Naturalness and Biodiversity

Restoration to a more natural condition can produce many different specific resources of significance and at different rates of recovery. The value of some of those resources varies with social context—for example, the value of increased discharge from a wetland area depends on the location of those who might make use of it. Therefore the unit-product value varies from one project location to another and their contribution to national benefit can vary widely. Other product values are less situational and more constant across projects nationally.

Study of ecosystem disturbance and recovery reveals that functions in general restore at a faster rate than species diversity as indicated in Figure 3.4. Most of the major functions of ecosystems restore relatively quickly following natural and moderately destructive events, such as fire, drought, flood and storm (curve A in Figure 3.5). This is the restoration process associated with the more traditional pattern of ecosystem resilience. Typically, a few pioneer species enter quickly from the adjacent intact ecosystem and restore much of the production, biomass, mineral flow and cycling, hydrologic effects, functional resilience, and functional sustainability early in the natural restoration process. Much of the structural biodiversity associated with rare species follows later (curve B in Figure 3.5), mostly adding functional redundancy to the ecosystem. In complex ecosystems, the pioneer species often become less dominant as ecosystem conditions are altered by the inhabitant community and by those species arriving later in the recovery process. Some of the late arrivals may eventually become the dominant species. While the globally rare species are most often associated with the most structurally diverse condition of ecosystems, they can also be associated with any stage along the continuum from fully disturbed to fully recovered.

This implies that those natural functions and services closely linked to biomass and production dynamics will often recover at faster rates than services associated with the rare structural attributes aligned with scarce species. Services associated with water supply for navigation, irrigation and domestic use; flood damage reduction; commercial fisheries; fish and wildlife based recreation; natural features-based sight-seeing, erosion control, water quality treatment, and carbon dioxide regulation may become reestablished for the most part long before services associated with the rarest species become established along the gradient of partial to full restoration. In at least some cases nonnative species can reestablish many of these specific functions and services associated with community production and biomass about as well or better than the native species (as discovered by the early "restoration" professionals who often "planted" non-native species to control erosion, to provide fish and wildlife-based recreation, and to "protect" watersheds.

An important natural service associated with the later arrivals to a fully recovered biodiversity is a functional redundancy service. Redundancy provides ecosystems with optional parts, which may assume a higher functional profile when conditions change in the ecosystem environment. Functional redundancy adds to the resource development options associated with globally rare species. Ecosystems provide a basic service by sustaining those options. Of course, the more globally important service that is often associated with the scarce biodiversity in ecosystems, is the maintenance of genetic information that is vulnerable to extinction. While the values of many ecosystem services depend on distributions of resource supply and demand, the value of nationally significant biodiversity does not. What usually makes ecosystems unique and rare is the global rarity of their endemic species, regardless of where they occur in the Nation. The greater the number, uniqueness, and vulnerability of species at risk, the greater is the deficiency in ecosystem value that needs to be restored. Such a metric is comparable within and across ecosystems at local and national (or international) levels. Few other measures are universally of constant value across the nation (carbon sequestration may be one), but none are, according to national policy, more valuable.

In generally modified and intensively stressed ecosystems, the relationships between restored function and structure becomes even more difficult to predict with increasing probability that a new stability regime will become established. A new regime may result in different functional and structural performance, and may include few of the rarest species associated with the desired restoration condition. The new stability regime might be suitable for other rare species, but because it is out of context with the surrounding ecosystem, those species may never re-colonize.

Restoration can produce many different specific resources of significance. The value of some of those resources varies with social context—for example, the value of increased discharge from a wetland area depends on the location of those who might make use of it. Therefore the unit-product value varies from one project location to another. However, some products are more constant across projects Nationally and are amenable national summation of benefit produced. One measure is based on the genetic uniqueness of scarce biodiversity in the form of species at risk of global extinction. What usually makes ecosystems unique and rare is the global rarity of their endemic species. The greater the number, uniqueness, and vulnerability of species at risk, the greater is the deficiency in ecosystem value that needs to be restored. Such a metric is comparable within and across ecosystems at local and national (or international) levels.

3.3.8 Evaluating Projects and Priority Ranking of Ecosystem Restoration

Ecosystem outputs *in themselves* provide no indication of their social significance. Except when they become very scarce with respect to social wants and needs, the total amount of community production, biomass, materials of any kind, including water, or biodiversity fail to provide consistent clues to their social significance. In aquatic systems, high community production often signals low economic value per unit of production because the more valued commodities are associated with low-production states in which the commodities themselves are relatively scarce. Wetlands, in contrast, are typically high-production ecosystems providing resources and services that are now valued highly enough *in general* to establish a national goal of no-net-loss of wetland function and area. This goal came about because wetlands were perceived to be relatively scarce ecosystems that were rapidly being converted to other uses before their *specific values* were completely determined. Similarly, the extinction of species is resisted by provisions of the Endangered Species Act, including species with no known existing use but with possible individual and aggregate value yet to be determined.

There is often no close connection between *local* biodiversity and the resource significance and value in many ecosystems. A large proportion of the world's species are

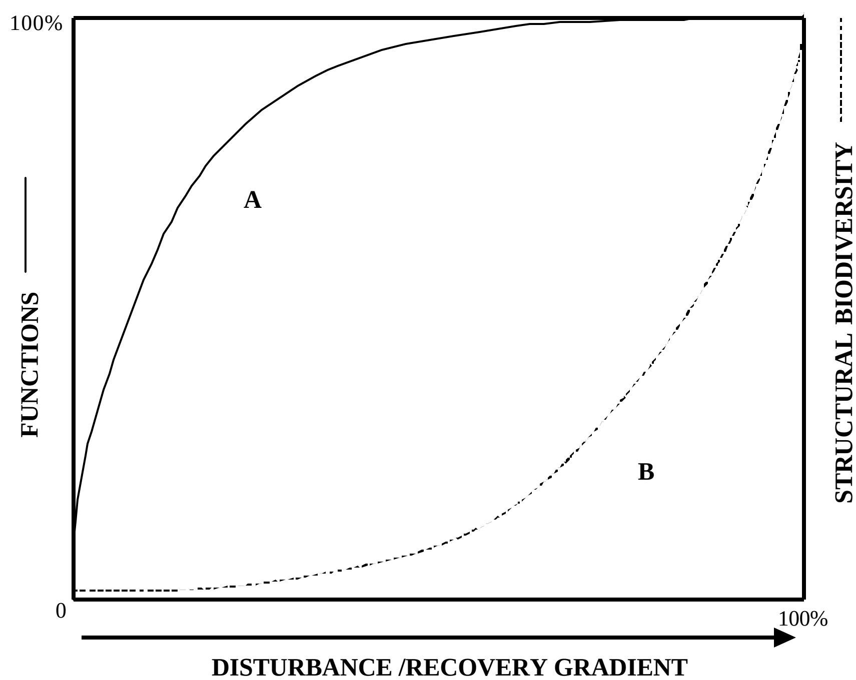

Figure 3.5. Generalized recovery rates of ecosystem functions associated with community production and structural biodiversity following local disturbance in an otherwise intact ecosystem. Causes of disturbance include storm, flood, drought, severe fire, agriculture, dredging or other stressors. A indicates the relatively rapid rate of recovery for many functions and services associated with production and biomass recovery. B indicates the slower rate of individual species recovery, with species on the right side of the recovery curve mostly providing functional redundancy.

not so scare they are at risk of extinction and their collective diversity has modest positive economic value, such as that associated with recreational sight-seeing and nature observation (e.g. birding). The most productive species range from low-value "weed", 'nuisance", and "pest" species to high-value "resource" species, the value being indicated less by the total supply and more by the relationship of supply to demand. Even when ecosystems have relatively high biodiversity, but composed of common species, they are not especially valued for sustaining their biodiversity independent of recreational and other such economic value, and are often converted to more highly valued uses, such as back yards and recreational reservoirs. Many substitute sites of equal biodiversity exist for recreational or educational use. In contrast, a number of ecosystems with low total biodiversity are protected from conversion to any other use than support of their biodiversity because much of that biodiversity is globally scarce.

Relative *scarcity of resources* is the key to determining most of what are held to be significant services via institutional laws, public opinion, and technical assessment suggested by the Water Resource Council (1983). Once ecosystem parts and processes become hard to get or are gone altogether, management choices become more limited. Restoration options diminish with the attrition of unique ecosystem structure and function.

Thus *a "keystone" priority* is secure maintenance of all ecosystem parts and processes vulnerable to extinction. Recovery to a more secure status ought to be high priority. The protection and recovery of endangered species authorized in the Endangered Species Act, regardless of all but the most onerous of social costs, is the primary institutional evidence of the non-monetary value attached to environmental sustainability through its living species. Held within the genetic information and traits of species vulnerable to extinction is the potential for resource development with global benefit. Loss of those traits and genetic information limits resource development and management options. Among the most important lost options is the ability to fully restore ecosystems. It is difficult to conceive of non-monetary benefits more important than the benefits associated with sustaining the rare parts and processes of ecosystems.

The potential exists for ranking relative non-monetary benefit based on the amount of genetic information and associated species traits that might be made more secure for the future. Recent studies have already been conducted primarily for the purpose of identifying ecosystems for conservation attention based on the global scarcity of their biodiversity (Stein et al. 2000, Abell et al. 1998). In ranking ecosystems with respect to the scarcity of biodiversity, the methods used by conservation biologists consider both uniqueness and vulnerability. DNA analysis and other molecular techniques can aid this process and will increase in importance in the future, but, in the near term, practicality dictates that the identification of species and community uniqueness relies mostly on more traditional taxonomic methods.

The uniqueness of a site's biodiversity is typically determined by the number of closely related forms within taxonomic categories. Final scarcity rankings are established after considering uniqueness at each taxonomic level. For example, a subspecies that is the only member of its species, genus and family is ranked much higher than a subspecies that is one among many other subspecies, in one of many species, in one of many genera in a family. Ecosystems harboring numerous globally unique families represented by one to a few species are ranked much higher in uniqueness than ecosystems made up of a few globally widespread families composed of numerous species.

Vulnerability to extinction is based on population factors such as relative abundance, distribution, reproduction rate, mortality rate and the intensity and imminence of new threats. A species classified as vulnerable implies that it is overly scarce with respect to its prospects for continued viability. A species of high total abundance that is widespread and has a reproduction rate that counterbalances mortality rate is ranked low in vulnerability compared to a species of low abundance concentrated in one geographically small location where there is little indication of successful reproduction. Biotic communities and ecosystems can be ranked based on the multiples of uniqueness and vulnerability summed to a biodiversity scarcity score. A community that has numerous species that are the sole members of their genus and family and are highly vulnerable is ranked higher than a community with few such species.

A number of government and nongovernment organizations use some kind of scarcity ranking method based on attributes similar to what is described above. Widely accepted methods used in the U. S. to rank global vulnerability of species are illustrated in the database, NatureServe (http://www.natureserve.org/explorer/index.htm), which was developed for the state natural heritage programs and The Nature Conservancy. The method is also described in Stein et al. (2000). Uniqueness ranks have undergone substantial theoretical development (NRC 1999b), but have yet to be incorporated into a national database. Management priorities for the Endangered Species Act are based in part on uniqueness as generally described above and there species are internationally ranked by the International Union for the Conservation of Nature(IUCN). Vulnerability and uniqueness classification methods require the knowledge base and skills of taxonomic specialists. They rely on a variety of classification and population evaluation techniques, subjective judgment, and peer consensus.

It is much easier to see the utility of ranking species and community scarcity in a national portfolio of restoration priorities than it is in determining whether or not biodiversity in a project area is scarce enough to consider it nationally significant. Because a gradient of biodiversity scarcity exists, there is no natural “threshold” that signals when a species or community is scarce enough to determine it is a “significant resource” as defined in Corps planning policy. The red lists of various organizations provide guidance, and, institutionally, the species listed under the Endangered Species Act would have high priority. But because many species that may deserve listing are still under consideration, a larger number of species undoubtedly qualify. Whether or not it is an artifact of status categorization is a relevant question, but the ranks of vulnerability indicated in NatureServe break out into relatively secure species in the G4 category and somewhat vulnerable species in the G3 category. In any case, determining the significance threshold will require judgment, which might be applied at the national, division or district level, depending on institutional policy.

To the extent that various biodiversity indices and process models might capture all of the habitat needs of the scarcest biodiversity, they may serve effectively to indicate the relative non-monetary benefit based on the increment of species security promised by the restoration action. Biodiversity models driven by community habitat variables are most often calibrated from the responses of the most abundant species in the system. Such models are least dependable for guiding recovery of the scarcest biodiversity. An effort has to be made to integrate their needs into the planning process, or at least to assure that their needs will be met by the needs of the more common species. This can be done by using community models and species or guild models in sequence, first formulating for the common biodiversity and then evaluating for whether the conditions provided are suitable for the significant resources. When both types of models are well calibrated, the habitat conditions indicating greater native biodiversity in a community-habitat model may be input into species-habitat models (or other model of resource significance) to determine the extent of biodiversity restoration required to restore for the resource of significance. This approach requires substantial coordination of model development and calibration through a carefully considered concept of the target ecosystem.

A uniqueness-vulnerability index falls far short of representing all value provided by natural ecosystem service. This index is based on the relative scarcity of species traits and genetic information, and it places high value on maintenance of the scarcest species for future management options, including restoration options. It places very little value on common species, despite the many ecological services that are provided by common species (They dominate the production, biomass and other ecological process underlying many services). Most utilitarian values, including NED, are associated with relatively common species, such as the species that support hunting, fishing and much other outdoor recreation. There may also be services and values as yet to be revealed that fall outside this index and the NED monetary index to value. Until those values are revealed, however, a uniqueness-vulnerability index is a good interim measure of NER contribution worthy of serious consideration.

3.4 Ecosystem Inputs: Management Measures and Natural Process

3.4.1 Natural Process and Management Measures

The *management measures* used in ecosystem restoration projects led by the Corps and other management agencies are inputs, the costs of which are justified by the promise of a gain in desirable ecosystem outputs. The natural ecosystem inputs required to sustain ecosystem biodiversity, integrity, and associated functions and services include all of the environmental forces and constraints that operate and regulate the system from outside including the motivating energy (usually solar, gravity, and chemical energy); the topographic, geologic, and hydrologic features; and all of the associated natural biodiversity. Among these inputs some are more subject than others to cultural modification and to management measures. While some of these forces and constraints are not manageable, many are.

Because different ecosystems take their unique form and function along a gradient of environmental forces and constraints, *the functional outputs from an ecosystem often become inputs for other ecosystems.* Water flow is among the most obvious examples in the Corps management domain, as it moves under the force of gravity through subterranean routes to surface streams over channel gradients and through basins to wetlands, aquifers, lakes, rivers and estuaries. Along the way it erodes, transports and deposits an assortment of organic and inorganic materials transporting them from ecosystem to ecosystem. Most Corps management measures shape basins, channels, floodplains and beaches to create or restore interactions between water, gravity, substrate, water-transported materials, and living communities.

Project location with respect to natural influences from the surrounding landscape and random events is among the more important input considerations when forecasting the without project condition and when choosing management measures for project plans. While the Corps most commonly considers “habitat measures” as most relevant to recovering a significant natural resource through ecosystem restoration, restoration measures may also influence ecosystem structure and functions other than the organisms that inhabit the habitat. Examples include filtration of particulate materials, the absorption and biological incorporation of dissolved materials, the percolation of water to ground water aquifers, surface and subsurface storage and discharge of water, and other functions in support of ecosystem services. The incidental economic and other benefits that might be associated with these structural and functional changes need to be considered to complete the planning process.

3.4.2 Random Events and Ecosystem Inputs

Random events contribute significantly to the way ecosystems function and respond to restoration measures. Species are adapted to and sustained by the natural variation of ecosystem processes, including variation resulting from random events associated with storms, floods and fires. Ecosystem integrity depends on the maintenance of variation caused by random events, which affect the colonization success of species and the resulting species composition of the restored community. The composition of rare species is most likely to change from the original composition because of random events.

The Corps operates in ecosystems influenced by random events associated with weather, hydrology, hydraulics, and community recovery process. The uncertainty associated with random events cannot be reduced without diminishing certain desirable natural services resulting from ecosystem restoration. That same variation often is modified through installation of artificially engineered structures and functions. Partial to full ecosystem restoration requires at least some reversal of this modified state either by returning natural process or by artificially simulating the variation.

Random events introduce *unavoidable uncertainty* into prediction of ecosystem integrity at any one location and time. Accommodation of that source of uncertainty typically requires adjusting the scale of planning to a larger sphere of ecosystem connection and influence. The uncertainty associated with ignorance of functional effects, which by definition are predictable if understood in an ecosystem context of proper scale, is avoided through improved understanding of ecological process. Improved understanding of functional cause and effect usually requires searching for cause at a broader landscape scale of ecosystem investigation.

3.4.3 Landscape-Scale and Ecosystem Inputs

Ecosystems reveal a widening range of properties when viewed through increased spatial and temporal scales. The species in ecosystems are adapted to the decimating effects of destructive random events through their *habitat connections* to unaffected parts of the same ecosystem or other ecosystems inhabited by those species. To be effective in restoring ecosystem integrity, as indicated by biodiversity, restoration measures must address the condition of these connections at a landscape scale (Norton and Ulanowics

1992). Ecosystems are hierarchical organizations that comprise numerous interactive subsystem “units” nested within more inclusive systems defined by spatial and temporal boundaries (O’Neill et al. 1986, King 1993). In the example shown in Table 3.2, ecosystem boundaries could be defined on a scale ranging from the microbial community in an insect on a rotting log located in a floodplain wetland to the entire watershed linked to the river and wetland. The numerous organisms, logs, and other subsystems contribute to the wetland ecosystem and many different wetland, pond, stream, and other riparian

Table 3.2. Simple example of spatial and temporal hierarchical ordering of a floodplain wetland ecosystem in a watershed context.

SPATIAL & TEMPORAL SCALE →					
	SMALLEST			LARGEST	
ECOSYSTEM	**INSECT GUT**	**ROTTING LOG**	**FLOODPLAIN WETLAND**	**RIVER & FLOODPLAIN**	**WATERSHED**
STRUCTURAL COMPOSITION	**bacteria**	**insects**	**rotting logs**	**wetlands**	**rivers & floodplains**
	protozoa	**fungi**	**cypress trees**	**ponds**	**headwater streams**
	water	**algae**	**birds, fish**	**lowland forest**	**headwater wetlands**
	nutrients	**water**	**decomposers**	**sandbars**	**lakes, ponds**
		air	**sediment**	**alluvial soils**	**upland prairie**
		nutrients	**water**	**riparian communities**	**upland forest**
TIME FRAME	**Weeks**	**Years**	**Centuries**	**Millennia**	**Many millennia**

subsystems contribute to the floodplain ecosystem. In turn, floodplain and upland ecosystems contribute to the structure, functions and services of a larger watershed ecosystem.

Ecosystems low in the hierarchy depend more on functional outputs from larger ecosystems high in the hierarchy. The insect could not survive without the log, which would not be there without the forested wetland, which depends on floodplain groundwater maintained by watershed runoff from a wilderness watershed. If the watershed is logged, surface runoff will increase the wetland sediment loads filling the depression as groundwater level drops and the aquatic community dies. A totally new array of species then colonizes the site. Small ecosystems come and go relatively rapidly compared to larger ecosystems depending on the events that shape them A floodplain wetland may last until the next major flood fills it with sediment, but other wetlands persist or are created in the process, sustaining the same general pattern and all of the component species. Holling et al. (1994) described in detail the relationship between event frequency and spatial scale of ecosystems for the Florida everglades.

Restoration of a filled wetland depends on the pattern of all wetlands in the floodplain, including habitat connections enabling colonization of the restored site to something like the original diversity and composition. That natural pattern can change, however, as upstream watershed and river channel conditions change from human impact, influencing both the total species pool available for colonization and the connections enabling colonization.

Ecosystem scale is a critical consideration for understanding the interdependencies of ecosystem functions and for plan formulation and evaluation of ecosystem management decisions (NRC 1986). Many of the failures encountered in past restoration attempts derive from insufficient ecosystem perspective when considering management measures. Corps ecosystem restoration activity often is based on the assumption that the establishment of the rudimentary physical attributes of habitat will be most certainly followed by self-restoration of the community. "If we build it, they will come", is too often the naive philosophy behind a provincial approach to restoration. Habitat restoration measures often amount to reshaping a basin or channel to more natural lines, supplying it with more-natural water-flow variation, perhaps seeding or planting it with one or two native plant species, then leaving it for nature to finish the job. The assumption that restoring a more natural physical state will assure the recovery of the justifying resources of significance because of the many pathways and uncertain processes by which unsatisfactory results can occur.

Restoration projects usually fail when the connections of the proposed habitat and community to other natural ecosystems are not restored in proper regard for all of the recolonizing organisms. Common setbacks for small restoration projects include destruction of restoration measures by "pest" species, disease, floods, droughts, wind, fires and other natural events. A significant service of integrated ecosystems is natural pest control. A freshly planted field without a full complement of predators and competitors is a banquet in waiting for the first hungry guests to arrive. The landscape scale and context considered in the restoration process can open or close ecological doors determining success and failure. A riparian restoration planting surrounded by natural vegetation harboring diverse predators is more likely to succeed than one surrounded by unvegetated terrain. A diversity of plantings of different size, species and distributions also can encourage more diverse colonization early in the natural restoration process.

At small restoration scales, onus is placed on the ecosystem manager to identify the many connections that need to be made to the larger ecosystem context to assure a specified level of restoration. At larger ecosystem scales, many of those connections become part of the internal structure and process, and less likely to be overlooked. Random climatic and biological events can overwhelm ecosystem restoration measures more often at small restoration scales. The effect shows up when small restoration projects are "wiped out" by a single storm event or even a busy beaver. In a larger restoration action only part of the project would be affected by the same random event and more comprehensive planning would provide for local recovery from an adjacent preserved or restored area.

Existing ecosystem models are most often least effective in identifying the proper ecosystem context and habitat connections that will serve as the source of colonizing species. This is especially true of simple index models, although some are conceptually better than others. They also are incapable of assessing the uncertainty of recovery as proposed in objectives. These missing elements are left to the professional judgment of planners who, because of many pressures, tend to narrow focus and assume "if you build it, they will come".

The concepts of habitat, biotic community, and biodiversity are scale dependent. The biodiversity of an acre of restored habitat depends on how that acre of habitat is situated within the larger area of that same habitat, and with respect to all other separate habitats and their associated communities in the inclusive landscape. Numerous larger species derive their sustenance from a number of different habitats with different biotic communities. When present in the community, they may have a dominant effect, such as many migratory mammals, birds and fish. For a far-ranging species, the community biodiversity indicative of supporting ecosystem integrity and the effect of the far-ranging species often extends over several discrete communities and habitats. Some of these species are keystone, having disproportionate community effects. Measures taken in one habitat may not have the intended effect if the support integrity of any other subsystem also is impaired. Ecoregional determinations of vulnerable species (e.g., Abell et al. 1998 and Stein et al. 2000) include some species that range well beyond ecoregional boundaries, such as migratory fish and birds. Whether or not local measures will be effective in restoring integrity, including species at risk, often depends on the status of ecological limitations in all habitats and communities influencing species viability.

3.5 Section 3 Summary and Conclusions

Environmental benefits analysis for Corps ecosystem restoration projects seeks identification of widely applicable non-monetary indicators of environmental value consistent with Corps policy. It requires definition of relationships between habitat and inhabitants to forecast indicator response to restoration plans, including a no-action plan. Ordinarily, Corps policy limits the choice of indicators to measures of function, structure, and dynamic process that reflect the condition of socially significant resources and are consistent with a more natural ecosystem condition. Ecosystem restoration benefits are to be measured in terms of changed resource quality that is a function of habitat improvement. Because habitat is defined by the living species and communities that inhabit them, the resources to be measured are expected to be the product of the living inhabitants—species, communities and their effects on the physical environment.

Because some benefits from restoration may derive from the purely physical effects of altering topography and hydroregime, it is likely that evaluation based on inhabitant effect alone would not capture all value in the Federal interest, as noted by the NRC (1999b). However, when done completely according to Corps policy the sum of all significant monetary and non-monetary effects resulting from the project should be considered, regardless of whether they were objectives of plan formulation. This should capture all significant effect in the Federal interest based in the material changes that occur in ecosystems, but it is unlikely that any single widely applicable non-monetary measure would cover all of those effects. Any socially significant effects that are not linked to the material consequence of restoration would not be included however. Thus, for example, the value perceived by some in the removal of an engineered structure alone, without concern for what material results in the ecosystem, is independent of ecological concept and measure.

In some cases greater naturalness of community-habitat complexes may provide in itself the service of significance, but in many other cases only a subset of resources may be recognized as significant. Corps policy requires that all significant benefits and costs accruing to restoration plans be considered in the local and national perspective for the selection and recommendation of a plan. Thus, in addition to the biotic resources of significance, the value of all other biotic and abiotic output from restoration should be considered. Restoration can be total or partial, but the desired result is a self-regulating, sustainable output of resources that provide significant natural service.

Ecological concepts pertaining to measures of naturalness and to individual living resources and their products in ecosystems include ecosystem structure and function, biodiversity, ecosystem integrity, production and other energy flow, material flow and cycling, self-regulation, sustainability, resilience, and redundancy. These are related ecological concepts, but vary enough from one another in response to restoration that they cannot be comfortably considered either as one or independent in project formulation and evaluation.

Ecosystem integrity is a promising concept for guiding the restoration of ecosystems to conditions with less net human effect, or greater naturalness. In practice, ecosystem integrity is indicated by the biodiversity and physical features and processes that occur in along a gradient of human effect in reference ecosystems. Broadly defined measures of biodiversity are the most inclusive measures of ecosystem integrity, and also appear to be the most inclusive measures of the resources targeted for restoration in Corps policy. However, ecosystem integrity has little meaning outside of the context of ecosystem reference conditions. A unit of natural integrity, measured by some increment of biodiversity, has no universal meaning across ecosystems, and, as now conceived, cannot be summed in some meaningful evaluation measure of contribution to ecosystem integrity accross ecosystems at a national level. Thus it seems to fall short of a measure adequate to NER evaluation needs.

The long-term continuity of function and structure in an ecosystem, or ecosystem sustainability, is often linked to naturalness and an intent of ecosystem restoration. Sustainability can occur in a wide variety of ecosystem configurations, however, including various levels of natural configuration and human effect, which, when desired by humankind, are known as cultural integrity. Sustainable conditions can result in very undesirable states, as well, such as the repulsive and unsanitary conditions of a river heavily polluted with human wastes. Thus sustainability in itself has little meaning as a measure for NER contribution. Like ecosystem integrity—whether natural or cultural—to which it is closely related, the sustainability added to NER by each project is only meaningful in a context defined by the desirability of the outputs provided. Because both preferences and structural figurations not only can but probably will change through time, ecosystem resources and services will vary in desirability through time. Establishing a constant structure and function at a project site, even if it were possible to sustain, would not be valued nearly as highly as future management flexibility that is responsive to preference changes while it maintains all future management options.

The restoration of and sustainability of future options requires a comprehensive landscape perspective that reaches to the entire ecosystem. The biodiversity of landscapes represented in the patterns of natural ecosystem reserves and their connections to restoration project areas is of critical importance in determining the success of restoration plans. Choosing which resources are most important to restore for maintenance of management flexibility, including future restorations when desired, is most determined by the distribution, vulnerability and uniqueness of scarce resources in the landscape. These are among the most significant of ecological resources. If not considered at a landscape level, overlooked effects and random events will ensure that substantial irresolvable uncertainty will remain in the restoration process, especially when the resources are very rare and the project area is very small.

Thus restoration of the most significant resources, based on relative scarcity, becomes particularly risky at sites embedded in highly disturbed ecosystems and landscapes. Managing the risk requires information about the relationships between the ecosystem needs of the significant resources and the degree of naturalness planned by ecosystem measures In contrast, the restoration of the common resources is relatively easily assured. Ecosystem functions and associated services such as production, biomass accrual, sediment control, nutrient sequestration, and green space development, and their sustainability are relatively easily recovered with recovery of the common contributors to biodiversity. These functions and services may be in short supply for local desires but are much less likely to be so scarce as to satisfy a national need.

Common biodiversity measures indicative of ecosystem naturalness and integrity are more useful for formulating for the most common natural conditions than they are for evaluating restoration effects on scarce resources at either a local or national level. But only when they are combined with condition measures for the significant resource. Partial restoration is especially unlikely to forecast response of rare structure if the common structure and function is restored at different rates, as seems to be indicated for many of the ecosystem conditions so far studied. In many cases, the rare species structure of ecosystems recovers much later in restoration process than many of the ecosystem-level functions (e.g., production, resilience, material flow and cycling) indicated by more common contributors to biodiversity. Because very few ecosystems have are unaltered to at least some extent by humans, very few can be entirely restored. However, if the ecological requirements of the scarce resources are known, forecasts of the ecosystem conditions sustaining a more natural biodiversity, can be used to evaluate the suitability of expected conditions for the resources of significance.

There appears to be no single non-monetary unit that is widely applicable for environmental benefits measure. No ecological output reveals more possibility as a universally applicable basis for non-monetary measure of service benefit than the energy in ecosystems. Energy is the most universally distributed natural resource found in ecosystem form and process that can be compared as Joules, calories, dry organic weight energy measure. Like naturalness, they provide little insight beyond power supply into natural or management-enhanced ecosystem service and values. A related concept of power maximization has been proposed, but remains obscure and peripheral.

A somewhat less universal resource, but found in all life process of ecosystems, is genetic information. It is the "blueprint" information needed to renew life through reproduction of the variety of form and function defined in biodiversity. Virtually all services rendered by life processes are defined and sustained by the genetic information held in an ecosystem context. The amount of genetic information is most usually indicated by measures of biodiversity—most often species richness. While efforts are made to account for all species, no community-habitat indexes are nearly so inclusive. Like energy and naturalness, genetic information in itself provides little insight into many of the natural and management enhanced services and values that depend on it. Like calories, the service rendered by genes depends on its expression in form and function, and that expression has to be calibrated against social recognition of its significance to define service and value.

Assuming that scarcity is an important criterion, one of the clearest categories of specific ecosystem output indicating resources of *environmental* significance are the threatened, unique traits held in rare species at risk of extinction. Until those traits are defined clearly in terms of their full service capability and value, their restoration and maintenance sustains resource-development possibilities, including ecosystem restoration options, which would be lost with extinction. Until science informs better, each gene of unknown potential holds equal option value, and a genetic or species-based currency can be conceptually based on uniqueness and scarcity of genetic traits (NRC 1999b). This currency would have little meaning otherwise. It would misrepresent the many resource values based on active utility of ecosystem resources. The common traits found in many plants and animals economically valued for their commodity and recreational use would have low increments of environmental value as indicated by this measure. While preliminary assessments of vulnerable species and their home ecosystems provide a good start, the development of a "currency" based on the scarcity of unique species traits and genetic information is incomplete and requires further investment.

Many other *environmental* service values (benefits) are affected by the restoration of ecological resources. Certain cultural resources may fall into this category, but are not the objective of ecosystem restoration, as defined in Corps policy, which precludes cultural and aesthetic attributes of the environment. The fish, wildlife, plant and other natural features underlying recreation may serve as nonmonitary indicators of value, but seem to be considered economic values rather than environmental values in Corps policy. Other non-monetary measures are possible for other services, such as those associated with water supply and flood damage reduction. But they too are typically considered among economic values. Regardless, however, once a restoration project is evaluated for its biological resource effect, Corps policy requires all monetary and non-monetary costs and benefits to be considered in evaluation. While the decision to restore may be based fundamentally on non-NED benefits becoming reestablished in significant amounts, all national benefit and cost effect is to be considered in the analysis. The findings here are consistent with the NRC (1999a) judgment that habitat-based measures of restoration benefit used alone are likely to under-represent the Federal interest.