7

System-Level Strategies for Conserving Rare or Little-Known Species

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In this chapter we review the literature on system-level strategies for conserving rare or little-known (RLK) species, continuing from the species-level approaches addressed in the previous chapter. We define system-level approaches as those that result in conservation actions focused on providing for community or ecosystem composition, structure, or function. See table 7.1 for a description and main assumptions of the system approaches we review.

As used generally in planning and management, system-level approaches to conservation do not necessarily or specifically pertain to individual RLK species or groups of species per se. Instead, they tend to emphasize the maintenance of ecosystem structure, function, and integrity as at-risk entities in their own right or as surrogates for individual species. We discuss the scientific merit and strengths and weaknesses of each approach for conservation of RLK species.

The organization in this section is based on criteria used in designing the approach. That is, if structural attributes of an ecosystem were used in developing an approach, we would classify the approach as "structural," even though the approach also influences the functioning of the system. Likewise, if the approach is based mostly on disturbance regimes or functional aspects of a system, we would tend to classify it as a "functional" approach.

Table 7.1. *Summary of system approaches showing descriptions and main assumptions*

Name of Approach	Description	Main Assumptions
	MAINTAINING SYSTEM STRUCTURE AND COMPOSITION	
	Maintaining System Structure Composition	
Range of natural variability (RNV)	Managing within a range of historic vegetation and environmental conditions	• Range of historic conditions represents conditions under which native species persisted, and under which modern humans had little anthropogenic or technological impact • Such conditions would provide for future persistence of species and systems
Key habitat conditions	Maintain a mix of conditions including types and successional stages of plant communities	• Appropriate habitat conditions can be identified by focusing on selected species, including species playing key ecological roles • A mix of habitat conditions will support the diversity of associated species
	Species that play critical ecological roles	
Keystone species	A species that regulates local species diversity in lower trophic levels	• Their effect on species diversity in lower trophic levels is disproportionate to their abundance • They perform roles not performed by other species or processes • Only a relatively few species within an ecosystem have such effects
Ecosystem engineers	Species whose activities modulate physical habitat	• Their effect on physical habitats and therefore ecosystem structure and function is disproportionate to their abundance • They perform roles not performed by other species or processes • Only a relatively small subset of species in an ecosystem serve these influences
	MAINTAINING SYSTEM PROCESSES AND FUNCTIONS	
	Maintaining disturbance regimes	
Fire	Restoration of historic timing, severity, seasonality, and size of fires	• Restoration of the fire regime will result in structural characteristics upon which many species depend and will ultimately result in a mosaic of structural classes that occurred historically
Herbivory	Restoration of historic patterns, intensity, and types of herbivory	• Restoration of historic herbivory patterns is important in systems that evolved with grazing and in those systems that were largely devoid of large herbivores

Name of Approach	Description	Main Assumptions
	Maintaining Other Ecosystem Processes	
Key ecological functions of organisms	Patterns of the major ecological roles played by species in their ecosystems	• Providing habitat for natural or desired numbers of species with specific key ecological function categories would ensure functionality of the system • Greater levels of functional redundancy impart greater stability and resilience of the system and ecological communities to external environmental perturbations • All species within a community perform some key ecological functions that can influence the environment of, or resources used by, other species
Food webs	Flows of substance and energy among feeding links and across trophic levels	• Providing for food chains within ecological communities can maintain the stability and natural dynamics of the community

Maintaining System Structure and Composition

This set of approaches pertains to maintaining the structure or composition of species assemblages or ecological communities, or maintaining the dynamics of ecosystems.

Range of Natural Variability

This approach focuses on maintaining the mix of ecosystems across the landscape within the historic range of natural variability (RNV) (Landres et al. 1999). An assumption of this approach is that native species of a region adapted to and occurred within some historic range of variability that can be estimated and potentially replicated by land management. This approach also assumes that maintaining the mix of communities within this natural range will provide for the current needs of associated species (Morgan et al. 1994; Agee 2003).

This approach is based on an understanding of "natural" structure, composition and disturbance regimes that existed when ecosystems were relatively unaffected by people. Such reconstructions of historic conditions depend greatly on the geographic area, time period, and specific conditions considered. Selecting a starting time, that is, deciding how far to look back, is an important consideration in historical reconstructions and in deciding how to depict the natural range of variability. Morgan et al. (1994) recommended that reconstructions should consider only the time period during which the current vegetation was in relative equilibrium with the current climate and other biotic factors. Based on this recommendation, Hann et al. (1997) used the last 2000 years for the Interior Columbia Basin Ecosystem Management Project.

Of course, this method presumes that equilibrium could be, and had been, reached. Longer reconstructions are useful for appreciating the role of climate change on ecosystems and disturbance regimes (Swetnam et al. 1999) and for considering evolution of adaptive phenotypes and behaviors of species. Millar and Woolfenden (1999) argued that a more appropriate analog for western North America might be the Medieval Warm Period (AD 900–1350). Gill and McCarthy (1998) used longevity of plant species that reproduce only after fire to help define the upper limit of fire return intervals, to help in fire planning; they suggested that this approach could be useful in cases with little presettlement information on fire return intervals. Unfortunately, such reconstructions—representing *pre*historic (i.e., prior to written history) conditions—typically suffer from a "fading record" problem characterized by decreasing reliability with increasing time before the present (Swetnam et al. 1999).

The common assumption in this approach is that recent historic conditions represent conditions under which native species evolved. This assumption may very well be false, given the very long span of time (or variable spans of time among different taxa) over which evolution proceeds, as well as the high level of even recent (Holocene) variation in climate and vegetation conditions. Thus it may be more correct to refer to the historic range of variation as representing conditions over which native species may have *persisted* rather than evolved.

An analysis of the RNV is often used to describe desired (future) conditions. However if this connotes static, fixed conditions of vegetation structure, composition, and distribution, and of other environmental factors, to be consistent with the concept of variation, including natural (and anthropogenic) disturbance regimes, the term may better be revised as "desired (future) dynamics" (Hansson 2003). Focusing on dynamic elements of an ecosystem, such as variation in fire regimes, climate, and hydrology, helps describe a range of possible future vegetation and environmental conditions. In this approach, the land and natural resource manager could then decide the degree to which the fit between historic and future variations would be acceptable, given management goals and objectives.

In one version of the RNV approach, historical reconstruction techniques have been used to examine a number of ecosystem attributes. In forested ecosystems, these include forest composition and structural attributes such as the relative distribution and patch size of forest types and even the tree and age class distribution within and among stands. We discuss here approaches focusing on structure and composition of ecosystems separately from those focusing on restoring disturbance processes (discussed later). But, in reality, most efforts to restore historic structural attributes rely on an understanding of disturbance regimes that created or maintained this structure.

Incorporating an understanding of the dynamic nature of vegetation is an important attribute of strategies to manage within some historic range of variability (Hunter 1991). Some RNV approaches begin with an objective of providing the diversity of structural elements in variable configurations and quantities, with the ultimate objective of maintaining the dynamic patterns and processes that are integral to ecological integrity (Aplet and Keeton 1998; also discussed later in this chapter in the context of maintenance of disturbance regimes).

Sources of information for reconstructing historical structural and community attributes of ecosystems include information from biological archives such as packrat middens (Betancourt et al. 1990), opal phytoliths (Kerns and Moore 1997), and plant macrofossils and pollen deposited in soils, lakes, and bogs (Jacobson and Grimm 1986). Other sources of information used in reconstructing structural and community attributes of ecosystems include documentary archives, such as photographs and diaries of early explorers, naturalists, scientists, and settlers. The usefulness of these sources of information is limited by uneven spatial and temporal distribution, and as a result might not represent all, and in some cases even modal, earlier conditions. In addition, these sources may reveal relative abundances of major species groups but cannot be used to address questions about the patchiness of vegetation types, the area or age class distributions of forest types, or occurrence and prevalence of plant species that are poorly represented in midden or pollen samples. These limitations are particularly troubling when dealing with rare species because specific mention of even their presence in historical documents is uncommon.

In spite of the difficulties in reconstructing historical structure and composition of native landscapes, this approach is widely applied in conservation efforts. Strategies aimed at ultimately restoring the natural distribution of ecosystems and seral stages must characterize how these patterns have changed. Central to such approaches is first assessing, at least regionally (and not just within the planning area), how coverage by major vegetation types has been altered by humans. Such analyses are useful in identifying vegetation types that are rare throughout their range and not just locally rare in the planning unit. This information can be used to prioritize conservation efforts on the more globally rare types.

Large-scale regional assessments may fail to address landscape features that occupy only a small area but support biodiversity elements, including RLK species. Simply preserving uncommon habitats such as wetlands, fens, bogs, springs, riverine systems, and other unique habitats is an important step in meeting species diversity goals. For example, protection of springs and sphagnum bogs was deemed necessary for maintaining some rare insects in eastern Oregon and Washington forests (LaBonte et al. 2001). Maintenance of habitat features such as wetlands, riverine systems, sandhills, and caves, plus prairie dog (*Cynomys* spp.) colonies and concentrations of Richardson's ground squirrels (*Spermophilus richardsonii*) was needed to support a number of threatened and endangered species of the Great Plains (Sieg et al. 1999).

A number of strategies using an understanding of RNV are aimed at one specific vegetation type. For example, Prober (1996) quantified floristic composition and soil types in remnant *Eucalyptus* woodlands in Australia. These data were then used to design reserves that would include sites representative of the natural variation and that would compensate for high losses of woodlands on soils suitable for agriculture. In another example, the U.S. National Park Service used a combination of repeat photographs and tree ring evidence to document recent tree invasion of a montane meadow in New Mexico (Swetnam et al. 1999). This information was then used to develop a strategy to restore the grassland character to this region. Reconstruction of historic stand densities, as well as tree size and arrangement, and fuel loadings are key components of strategies designed to restore southwestern U.S. ponderosa pine (*Pinus ponderosa*) forests to conditions more typical of late 1800s reference conditions (e.g., Fulé et al. 2002).

The U.S. Department of Agriculture (USDA) Forest Service has used various versions of RNV-based strategies in developing land and natural resource management plans. For example, management guidelines for an area in southern Idaho were designed to maintain habitat types or fire groupings of stands within a historic range of conditions. Other examples of applications where RNV principles have been used focus on identifying and restoring within-stand structural components. For example, a comparison of historic to modern photographs taken from the same photo points can be used in developing range management and restoration plans (Skovlin and Thomas 1995).

RNV approaches can also be used to aid understanding of historic vertebrate and invertebrate species composition. Such information may be used in conservation strategies in a number of ways. First, this information can identify species that have been extirpated from the planning area, and consideration can be given to their reintroduction. This information can also help identify species that are now more or less common relative to presettlement periods. The presence of specific wildlife species can also provide valuable information about habitat conditions at the time. For example, lists of birds and estimates of their abundances compiled by naturalists in the late 1800s and early 1900s along the Missouri River provided insights into the composition and extent of riparian woodlands at that time (Rumble et al. 1998). Observations on the presence of ducks, fish, and frogs throughout the year and in drought years give some sense for whether historic lakes supported persistent populations of aquatic animals and species (Severson and Sieg 2006). This type of information is potentially useful in setting more informed restoration goals.

Regardless of the approach, efforts designed to restore the structure and composition of native landscapes are fraught with implementation problems. Areal coverage of some ecosystem types such as tallgrass and rough fescue (*Festuca hallii*) prairies and longleaf pine (*Pinus palustris*) forests have been reduced to such a high degree that restoration of even a portion of the historic range of variation seems unlikely (Klopatek et al. 1979). Species extinctions, geographic fragmentation, continued human expansion, exotic species introductions, and changes in atmospheric gases are among the other impediments to restoring historic structural and compositional diversity to native landscapes (McPherson 1997), as are social and economic costs of resource (re)allocation, and possibly climate change.

Effects of all of these impediments on understanding historic distributions of RLK species and their restoration or conservation are largely unknown for most such species.

Diversity of Habitat Conditions

This set of approaches focuses on how species use diversity of habitats and conditions, but not from the perspective of historic or natural variation. We describe two approaches: managing for key habitat conditions, and managing for species that play critical ecological roles.

KEY HABITAT CONDITIONS

An approach based on key habitat conditions is an example of a "coarse filter" strategy (see chap. 4), where the goal is to maintain a mix of habitat conditions at an appropriate management scale (Kaufman et al. 1994). However, this approach is not specifically tied to an understanding of historic range of variation. The assumption is that restoring or maintaining a mix of seral stages will provide the range of habitat conditions to support the diversity of associated species (e.g., Oliver 1992; Hof and Raphael 1993). In some regions, dense human populations and fragmentation of remaining habitats prevent management designed around natural disturbance regimes (Litvaitis 2003). Examples using this approach include Haufler et al.'s (2002) "adequate ecological representation" approach, whereby the management goal is to maintain a minimum of 10% of the maximum of the range of historical conditions of each community type. To aid in the recovery of Pitcher's thistle (*Cirsium pitcheri*), a threatened species in the United States and Canada, early-successional dune habitats are maintained (McEachern et al. 1994).

SPECIES THAT PLAY CRITICAL ECOLOGICAL ROLES

These approaches focus on restoring species that have large effects on community structure or ecosystem function that is disproportionate to their abundance or biomass and perform roles not performed by other species (Power et al. 1996). A number of schemes have been proposed for classifying species that play critical ecological roles. We discuss two examples: *key-*

stone species, which regulate local species diversity and competition, and *ecosystem engineers,* or species that modulate physical habitat.

The keystone species approach relies on the management for specific species that play major ecological roles in their ecosystems that influence many other species. Keystone species are species that regulate local species diversity in lower trophic levels, and whose removal results in significant shifts (increases or decreases) in the presence, distribution, or abundance of other species (Bond 1994). The term "keystone" was initially suggested by Paine (1966, 1974) in experiments in which mussels released from starfish predation took over the intertidal environment, and in doing so, reduced or excluded other species. Paine thus defined a keystone as a species (like the starfish) that kept other species in the system by keeping mussel populations in check.

The main assumption of the keystone approach is that some individual species disproportionately affect the distribution and abundance of either resources for other species or other species directly. The effect is directly causal from the keystone species' behaviors and is not just correlational. Further, the removal or decline in keystone species results in significant (and presumably undesired) changes in those resources or other species, and only a relatively few species within an ecosystem have such effects.

Since Paine's (1969) experiments, numerous species in many environments have been proposed as keystone species, including the coyote (*Canis latrans*) as a keystone terrestrial vertebrate predator (Henke and Bryant 1999), salamanders as keystone aquatic invertebrate predators (Wilbur 1997), and prairie dogs (*Cynomys* spp.) as keystone providers of ground burrows for other animals (Van Putten and Miller 1999). Even rare species can play keystone roles in some systems. Lyons and Schwartz (2001) reported that experimental removal of rare plant species, as compared with the same removal of dominants, led to greater invasion by an exotic grass species. However, this is not to say that all rare species play equally influential roles on community structure. Also, many little-known species (not necessarily rare) play keystone roles, particularly soil invertebrates that determine the structure and abundance of soil microbial populations (Moldenke et al. 1994).

Ecosystem engineers are species whose activities modulate physical habitats and thus have salient influence over community or ecosystem structure, composition, or function. Jones et al. (1996) defined ecosystem engineers as "organisms that directly or indirectly control the availability of resources to other organisms by causing physical state changes in biotic or abiotic materials." Butler (1995) described such animals as "geomorphic agents" and coined the study of animal ecosystem engineers as "zoogeomorphology." A main assumption of the ecosystem engineer approach is that, by their behaviors, particular species modulate physical habitats and thus have major influence over resources available to other species. Another assumption is that only a relatively small subset of species in an ecosystem serves these influences.

The American beaver (*Castor canadensis*) is a classic ecosystem engineer whose water-impoundment activities serve to increase plant and animal species richness within landscapes (Wright et al. 2002). Soil invertebrates are considered engineers of the soil environment, determining the structure and abundance of soil microbial populations and thereby influencing soil productivity (Moldenke et al. 1994). Smallwood et al. (1998) showed that the key ecological function of burrowing by animals is crucial to soil formation and is a critical link between geologic regolith material and organic soil life.

In summary, conservation approaches based on species that play critical ecological roles entail managing for species that have large effects on community structure or ecosystem function that are disproportionate to their abundance and perform roles not performed by other species or processes. Examples include keystone species that regulate species diversity in lower trophic levels or ecosystem engineers that modulate physical habitats. However, these functional-based conservation approaches tend to pertain to maintaining some aspects of ecosystem function rather than the occurrence and persistence of RLK species per se, unless those RLK species are themselves the species that play critical ecological roles.

Maintaining System Processes and Functions

These approaches are more process oriented; that is, they seek to restore and maintain the dynamics of ecosystem processes. We discuss two broad approaches: maintaining disturbance regimes, and maintaining other ecosystem processes such as food webs. Since it is not possible to discuss all terrestrial disturbances required to maintain ecosystem structure and function, we limit our discussion to two disturbance types for which we found conservation approaches: fire and herbivory. Similarly, we provide two examples of approaches designed to provide for other ecosystem processes: one related to providing key ecological functions and a food web strategy.

Maintaining Disturbance Regimes

Restoration of historic disturbances is increasingly being recognized as an important aspect of maintaining ecosystem structure and function. In disturbance-prone areas, environmental variability itself can be important to the life histories of many organisms (Aplet and Keeton 1998). Conservation strategies for rare species are increasingly recognizing the need to restore appropriate disturbance regimes.

Recognizing the importance of disturbance in maintaining heterogeneity of ecosystems has prompted increased efforts to assess, to the degree possible, how various disturbances in the past, such as fire and grazing, interacted with climatic fluctuations in maintaining community patterns. Characterizing and restoring historic disturbance regimes can be one facet of the RNV approach, discussed earlier. The main difference between these two approaches is that the RNV approach compares current or expected *conditions* to the range of historic or natural conditions, whereas maintenance of disturbance regimes focuses on the dynamics of *systems*, whether or not specific resulting conditions match some other historic or natural conditions.

Attributes of disturbance regimes that influence community structure, composition, and function include the type, severity, frequency, and seasonality of the disturbance and the size and shape of resulting habitat patches (Pickett and White 1985). Often, disturbances interact and their joint effects might be totally or partially additive (Frelich 2002). Altering disturbance regimes can have cascading effects on ecosystems—not just on disturbance-dependent species but also on species that occur in areas that are rarely disturbed. Studies are beginning to elucidate how disturbance processes at site, watershed, and even drainage basin scales can interact to maintain biodiversity (Everett and Lehmkuhl 1999), and how exotic species can influence plant community trajectories following disturbances (Hobbs and Huenneke 1992).

Studies of vegetation patterns, stand composition and age structure, and gap analysis and tree ring analyses of fire and insect events have been used to characterize historic disturbance regimes in forests (e.g., Dean et al. 1997). Charcoal layers in lakes and soils (Gavin et al. 2003) provide insights into the occurrence of past fires in some systems. In grassland ecosystems, tree ring studies from adjacent forests (Sieg 1997) and information from documentary archives can provide insights into past fire and grazing disturbance regimes (Severson and Sieg 2006). Long-term climatic reconstructions from tree rings often provide an understanding of how historic disturbances change with varying climates (Swetnam and Betancourt 1998).

As already discussed under restoring structure and composition based on RNV approaches, reconstructing past disturbance patterns is often difficult. Some ecosystems have crossed thresholds such that returning them to a previous state, or reinstating historic disturbance regimes, can be extremely challenging or impossible. In some cases, past management, introduction of exotic species, rarity of native species, and continuously expanding human populations make reintroduction of historic disturbance regimes quite difficult.

In some situations, it might make greater sense to focus on restoring disturbance regimes and letting specific conditions result as they may; in other situations, the focus may be on altering the conditions and then reintroducing natural disturbance dynamics. Stephenson (1999) characterized the tension between these two approaches as "structural restoration" versus "process restoration." Both may be useful in different circumstances. For example, reintroducing historic fire (a natural disturbance regime) into grasslands of the inland U.S. West that are currently heavily dominated by spotted knapweed (*Centaurea maculosa*) may result only in more knapweed and not serve to restore historic conditions per se. In this case, restoration activities might first focus on alerting the structure of the plant community (that is, removing the knapweed) and then reintroducing the historic disturbance regime. Stephenson (1999) cited an opposite example, where reintroduction of a fire regime without a preceding structural (mechanical) restoration might serve to restore historic conditions in groves of giant sequoia trees (*Sequoiadendron giganteum*), a globally rare but locally common species in the Sierra Nevada, California. The degree to which such structural versus process (disturbance regime) restoration approaches would be useful for conservation of RLK species would likely need to be determined on a case- and context-specific basis.

Much of the information used in maintenance of disturbance regimes pertains to the dynamics of systems and not to the presence and condition of RLK species. Thus the degree to which restoring historic disturbances to a system serves to conserve or restore any given RLK species may be largely unknown.

FIRE

Many conservation plans for fire-prone ecosystems call for restoration of historic fire regimes. Restoration of fire regimes is confounded not only by an incomplete understanding of past fires but also by the difficulties of returning fires to areas that are greatly altered in many other ways.

Even for well-studied ecosystems such as the tallgrass prairie of the central U.S. Great Plains, the limited area of remaining grasslands confines the scale at which fire treatments can be implemented and studied. In other systems, such as the pitch pine (*Pinus rigida*)–scrub oak (*Quercus ilicifolia*) barrens in the northeastern United States, restoring large-scale crown fires is hampered by the proximity of human settlements as well as by the small amount of barrens remaining (Jordan et al. 2003). For much of the ponderosa pine type in the western United States, there is a growing recognition that return of frequent, low-intensity surface fires is difficult without first mechanically removing trees and perhaps fuels (Fulé et al. 1997).

Some strategies that are based on understanding historic fire regimes attempt to emulate the structure that results from past fires without burning (Buddle et al. 2006). For example, Cissel et al.'s (1999) landscape plan prescribes timber harvesting in the Pacific Northwest to emulate past burning regimes. Similar strategies have also been attempted on other biomes.

A number of conservation plans incorporate burning guidelines that are modified to account for the needs of rare species. Gill and McCarthy (1998) recognized that variability in fire intervals in nature is inevitable and desirable in prescribed burning plans designed to conserve biodiversity, and that understanding the life histories and habitat requirements (and associated fire regimes) of rare species can be used to propose appropriate fire intervals. Lamont et al. (1991) estimated that a mean fire interval of 20 to 30 years would maintain a rare plant species (*Banksia cuneata*) in western Australia. Brooker and Brooker (2002) modeled the population of the splendid fairy-wren (*Malurus s. splendens*), and concluded that at least 20 years between fires allowed birds to establish territories (3 to 14 years). In another example, managing endangered Kirtland's warblers (*Dendroica kirtlandii*) in the Great Lakes states has entailed periodic logging and burning of jack pine (*Pinus banksiana*) stands to maintain early successional pine forests favored by the bird (Marshall et al. 1998). In many such examples, restoring fire patchiness and variability in burn intensity may also be important.

HERBIVORY

Historic patterns of terrestrial herbivory by vertebrate species have been altered in many, if not most, native ecosystems in North America. Alterations include changes in native herbivore composition and abundance as well as introductions of nonnative grazers. As a result, in combination with a declining habitat base and efforts to sustain economic livestock operations, the timing, duration, and intensity of herbivory by terrestrial vertebrate species in many systems is likely different from presettlement patterns. Plants (perhaps including some RLK species) in many forested and nonforested ecosystems evolved with some type of herbivory and developed a tolerance and even a dependency on herbivory (Collins et al. 1998), but the impacts of herbivory can be greatly altered by herbivore density as well as forage availability (Laurenroth et al. 1994). The introduction of bison (*Bison bison*) to the Konza Prairie Research Natural Area is an example of an approach that attempted to restore historic grazing patterns based on a perceived range of natural variability (Knapp et al. 1999). In an attempt to introduce heterogeneity in grazing levels, the USDA Forest Service (2001) Northern Great Plains plan proposed to alter livestock grazing management strategies to provide a range of levels of residual cover, based on the recognition that some rare species are dependent on heavily grazed sites and others require higher levels of residual cover for nesting cover.

Maintaining Other Ecosystem Processes

"Other ecosystem processes" includes a range of approaches to considering other ecosystem processes and ecological functions. We provide two examples here: one relating to key ecological functions (KEFs) of organisms and the other relating to maintenance of food webs.

KEY ECOLOGICAL FUNCTIONS OF ORGANISMS

KEFs are the major ecological roles played by species in their ecosystems (Marcot and Vander Heyden 2001; Marcot et al. 2006). Ecological functions of organisms support the trophic structure of ecosystems (energy flows, food webs, predator–prey relations, and nutrient cycling) as well as interspecific symbioses and other interactions that serve to structure ecological communities (Chapin et al. 1996).

Multiple species serving a similar function define the functional redundancy of the system. Theory suggests that ecosystems with greater levels of functional redundancy may be more resilient or resistant to adverse changes in their structure, composition, or function than are ecosystems with lower functional redundancy levels (Rosenfeld 2002). KEFs of species can ultimately affect ecosystem productivity, diversity, resource sustainability, and levels of ecosystem services.

One major assumption of the key ecological functions approach is that providing habitat for natural or desired numbers of species with specific KEF categories would ensure functionality of the system. Another assumption is that greater levels of functional redundancy impart greater stability and resilience of the system and ecological communities to external environmental perturbations. Yet another assumption is that all species within a community perform some key ecological functions that can influence the environment of, or resources used by, other species.

In the KEF approach, categories of KEFs, along with habitats used, are listed for individual species in a species–environment (or wildlife–habitat) relations database. The KEF approach was used in the terrestrial ecology assessment of the Interior Columbia Basin Ecosystem Management Project (ICBEMP) of the Forest Service and the U.S. Department of the Interior (USDI) Bureau of Land Management (Marcot et al. 1997). Several categories and patterns of functions and species were suggested as possible foci for ecosystem management under ICBEMP, such as imperiled KEFs (functions that may vanish from a system when performed by one or a few species that are themselves at risk), functional specialist species (species that perform only one or very few functions), critical functional link species (species that are the only ones in a system that perform specific KEFs), and functional diversity and richness of ecological communities (the number and variety of KEFs in a system). Further, an ecosystem that has retained all its native KEF categories can be defined as "fully functional." Resource managers could then determine the collective array of macrohabitats and habitat elements required by individual species (including RLK species, where their functions are known or suspected) or by a functional species group, pertaining to any of these patterns, and then craft management plans or prescriptions accordingly to provide for such habitats and thus the species and functions they support.

The KEF approach and its key assumptions are largely untested and, as currently implemented, rely on categorical and qualitative data on species' ecological roles. As presented, it is complementary to species- and habitat-specific management and thus does not presume to ensure any specific degree of protection or provision for all RLK species. Only in a general way, by fostering conservation of all ecological functions, does this approach provide for some (unspecified) degree of protection for RLK species.

Food Webs

Studies of food webs are similar to those of energy flow insofar as they relate flows of substance and energy among feeding links and across trophic levels. Food web studies have been a mainstream of ecological research for many decades. The assumption of the food web approach is that providing for food chains within ecological communities can maintain the stability and natural dynamics of the community.

Much has also been written on management of food webs (e.g., papers in Kitchell 1992). For example, Berlow et al. (1999) provided a set of indices by which food webs can be evaluated for use in management, including indices of predator functional response and the strength and importance of species interactions (keystone roles). However, there are few examples of land management plans, particularly for RLK species, that are based on food webs. The management strategy for northern goshawks in southwestern U.S. forests is a notable exception. These guidelines were structured around a food web strategy whereby the habitat needs of the primary prey species of the northern goshawk (*Accipiter gentilis*) were used to develop management guidelines (Reynolds et al. 2006).

One common theme in the ecological literature on food webs is that top predators in a food chain are usually uncommon and often highly sensitive to perturbations affecting the trophic structure of their ecosystem and their prey base (e.g., Lodé et al. 2001). Insofar as some RLK animal species are top predators, this principle may be used as a general guideline for their conservation, that is, by ensuring that their prey base and trophic web are maintained. Sergio et al. (2006) confirmed that top predators, used as flagship or umbrella species (see chap. 6), can justifiably be used as a basis for selecting reserves for overall biodiversity conservation.

Conclusion

The sets of system approaches reviewed here include those that focus on maintaining system structure and composition, as well as approaches that focus on maintaining ecosystem processes and functions. Collectively, such ecosystem approaches may provide for landscape conditions and ecosystem processes that match some natural, historic template, or otherwise normative and desired state, within which some RLK species may find suitable resources and habitats. These approaches account for the dynamics of entire systems in ways that species-specific approaches cannot. However, these approaches may entail managing for disturbance regimes that might harm conditions required by RLK species at specific locations. Also, instituting disturbance management guidelines or managing to maintain species functional groups may necessarily be based on imperfect knowledge of natural conditions and may suffer from problems of practicality of application.

Most system-level approaches to conservation strive to replicate some natural or baseline condition, ecosystem process, or dynamic disturbance regime. RLK species may play roles in mediating or determining such conditions, processes, and regimes, but system-level approaches may not necessarily ensure the conservation of specific RLK species. For example, an ecosystem might be performing within some natural range of variability of some parameter or disturbance regime, and it might contain a diversity of habitat conditions, and it might consist of desired ecosystem processes, but none of this ensures that particular RLK species would be conserved. That is, managing for RLK species is not necessarily the same as managing for biodiversity or for broader system-level performance criteria, conditions, and dynamics.

That said, it is likely true that system-level conditions and dynamics determine the quality of habitats and environments for conservation of RLK species. Thus the best approach to ensuring RLK species conservation may lie in some combination of species- and system-level approaches. The following chapter provides an evaluation of the effectiveness of the various species and system approaches for RLK conservation, as well as other management objectives, and chapter 12 provides an overall process for selecting among approaches.

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