Chapter 5

Conclusions and Discussion

Species Functions and Ecosystem Processes

In this report, we have expanded on initial frameworks and findings (Marcot and others 1997) of KEFs of species in the basin assessment area. We tried to demonstrate basic ecological relations among species and their environments that can lead the way to greater confidence in managing ecosystems for productivity and biodiversity. We have not dealt with riparian, wetland, or aquatic systems here, particularly with their unique constellations of species' functions and ecosystem processes. But they, too, are essential parts of landscapes and need to be integrated with the terrestrial portrait.

Our treatment of species functions—as with our geographic scope—has been broad, and many facets of ecological interactions of organisms bear further telling and study. For example, Willson (1996:101) lists six categories of direct mutualisms (species mutually benefitting) of organisms in terrestrial systems, including interactions among:

- Plants and animals (pollinators, dispersal agents, woody plants and protective arthropods, and vascular plants with extrafloral nectaries and animal protectors).
- Plants and fungi (mycorrhizal associations, endophytic fungi that decrease attacks on hosts by natural enemies, and lichens).
- Plants and micro-organisms (including nitrogen-fixing microbes and angiosperms).
- Animals and other animals (plant-feeding insects and ants, interspecific flocks and herds, and other cases of animal-animal mutualisms).
- Animals and fungi (spore dispersal of mycorrhizal fungi by small mammals, wood-boring ambrosia beetles and fungal gardens).
- Animals and micro-organisms (digestive aids, surface-dwelling microbes that provide protection with pathogens).

We have discussed some examples of many of these mutualist species relations. Other commensal relations, as well as predatory, parasitic, and other kinds of ecological relations, have helped shape the composition and function of ecological communities that we observe today.

The use of species function profiles and related analyses of species' KEFs can help to (1) determine the degree of functional diversity within communities; (2) identify communities with high (or low) redundancy in specific ecological functions, and therefore communities with high (or low) resiliency or buffering capacity in the face of disturbance regimes and systematic environmental changes; and (3) identify ecological functions with high (or low) redundancy among species, in particular communities.[1] Walker (1995) suggests focusing conservation attention on functionally important species groups with little redundancy; that is, with few representative species. We may extend his suggestion to include focusing conservation attention on communities with low redundancy in (or high variation among) ecological functions. Risser (1995) notes that biodiversity can affect ecosystem functions, and suggests focusing initial management attention on the key structuring processes at intermediate scales of space and time.

[1] All of these relations, particularly (b), need field validation.

Determining presence and redundancy of ecological functions also could be of help in posing specific goals for ecosystem restoration, particularly for augmenting natural ecosystems with restored ecosystems (Sinclair and others 1995) and by matching functional diversity in ecosystems undergoing restoration to that in undisturbed ecosystems. Examples of this include the use of species and ecosystem functions to monitor restoration progress in wetlands (Simenstad and Thom 1996) and to monitor trophic levels and feeding functions (shredders, grazers, and predators) of aquatic invertebrates in stream restoration projects (Murphy and Meehan 1991, Reeves and others 1991). Among terrestrial communities of the basin assessment area, studying patterns of ecological functions (functional redundancy and functional diversity) of forest seral stages targeted for restoration, such as old single-stratum ponderosa pine forests, could prove useful as monitoring benchmarks or to help define management targets.

Bioindicators of Terrestrial Ecosystem Health

In this report, we have further explored the potential use of lichens as bioindicators of various environmental situations, including old-growth forests, air quality, metal accumulation in soils, degree of soil acidity or alkalinity, fire and grazing regimes, and other conditions. As we discussed previously (Marcot and others 1997.), invertebrates also can serve as excellent early warning signals of existing or impending changes in environmental conditions. Sampling a small part of the invertebrate fauna, too, can help to index diversity of the entire invertebrate fauna. For example, Oliver and Beattie (1996) discovered that monitoring and assessment of terrestrial invertebrate biodiversity in Australian forests can be done by careful use of invertebrate morphospecies (species of the same morphologies)—principally ants, beetles, and spiders. Their results also suggest which invertebrate taxa to use, as well as sampling methods and sampling periods to yield the most consistent and reliable monitoring. In another study in the southern Appalachians, Hollifield and Dimmick (1995) censused arthropod availability and abundance, and they inferred from that suitability of logging roads, clearcuts, and mature hardwood forests for ruffed grouse (*Bonasa umbellus*). Other tests of plant or invertebrate indicators are presented by Nilsson and others (1995), and Murtaugh (1996) discusses statistical analyses of indicators. Although major surveys and systematics studies are needed on invertebrates in the basin assessment area, we feel that such bioindicator approaches hold great promise for rapid field evaluations of environmental conditions and of biodiversity in this region as well.

Past and Future Changes

It is evident that the basin assessment area has undergone tremendous prehistoric change in climate, habitats, and biota. Extinctions and originations of species, genera, families, and orders have occurred over spans of millennia or longer. We expect that natural extinctions, and hope that originations (including speciations and natural immigrations of native species), will proceed long into the future. Less extreme than extinctions and originations, we also expect changes in the geographic range of species' abundance patterns over time. For example, Kruckeberg and Rabinowitz (1985) note that some rare plant taxa might become common, and some local endemics might become widespread (although not as a rule), and that the fossil record provides many instances of widely distributed taxa that have become quite constricted over time.

Patterns of evolution and extirpation of species during the Quaternary cannot be discerned from modern conditions. Conversely, recent historic persistence of species probably cannot be used to discern conditions over which species have persisted in the very long term or under which they evolved. For example, some of the climatic regimes during the early Quaternary have no modern analogs, and interglacial periods were long and extreme enough to cause extinctions but not long enough for significant plant evolution (Tausch and others 1993).

Pollen analysis from Wildcat Lake, Whitman County, Washington suggests great changes in aquatic and terrestrial environments over the past 1,000 years, with the most significant changes resulting from livestock introduction and subsequent alteration of natural vegetation, the spread of weeds, and erosion, along with volcanism (Davis and others 1977). The response of

conifer vegetation to climate change may be rapid in the more arid steppe communities of the basin assessment area. Mack and Bryant (1974) report much pine pollen in Quaternary steppe communities of the Columbia basin, thereby suggesting potentially rapid dissemination and spread of pine during periods of favorable climate.

More important and perhaps surprising, Fritts and others (1979) report that climatic fluctuations in the Columbia basin during the 17th through 19th centuries differed significantly from those during the 20th century and included large-scale variations. The range of recent historic climate does not represent that of even just the past four centuries. Therefore, use of the range of natural historic variation in suggesting prehistoric climatic conditions, and associated vegetation communities and conditions under which species persisted or evolved, may need to be greatly revised.

We know that historic changes in vegetation conditions over the last two centuries have greatly diminished habitats for some species and increased it for others. A combination of activities (principally high-grade logging, forest fire suppression, and road building) have greatly enhanced habitat conditions for many species and imperiled it for others. Lessons from this project (chapters in Quigley and Arbelbide 1997) tell us that recent land management changes and growth of human populations in the basin assessment area have been accelerating, and that we need to pay better attention to the broad-scale and long-term additive effects of local extirpations and local changes to habitats and environments.

Although global and regional climate changes from increasing concentrations of greenhouse gases in the lower atmosphere are beyond the control of BLM and FS land planning, we can nonetheless project potential outcomes and inform publics and policymakers of effects.

One point of good news is that there is no evidence that acid precipitation is a major problem for wildlife in the basin assessment area as it is in other parts of the continent. Recent studies by Vertucci and Corn (1996) suggest that high-elevation aquatic amphibians—organisms highly sensitive to and excellent indicators of acid precipitation and degradation of water quality—do not seem to be incurring this problem in the Rocky Mountains. But this does not mean that populations of native amphibians are necessarily stable; some indeed are declining for various other reasons. Beyond the assessment area, amphibian declines and disappearances have been linked to quite a list of environmental woes including chemical pollution, acid precipitation, increased ultraviolet radiation, introduction of exotic species, pathogens, harvesting by humans, and natural population fluctuations (Blaustein and others 1994), as well as increasingly dessicating climates (Pounds and Crump 1994) and depletion of atmospheric ozone (Hileman 1994). We may consider amphibians as crucial indicators of conditions to come and may use this list of environmental assailants to check our progress over time. More localized current conditions and future changes also can be heralded by heeding the health of selected lichen, plant, and invertebrate populations.

Ultimately, the productivity of habitats and their biota depends on two main factors: solar energy and soil. Solar insolation fuels photosynthesis and primary productivity, which lie at the foundation of nearly all energy pyramids and food webs. Virtually the only exceptions are the ancient Archaebacteria—a group of methanogens, halogens, and extremely thermophilic acidophiles—that stubbornly persist in high temperature and pressure environments of thermal seeps in Yellowstone, Mount St. Helens, and deep ocean vents (black smokers)[2] (Baross and Hoffman 1985). There is not much we can do about ensuring solar insolation for the rest of the terrestrial biota, except to monitor changes in climate and the atmosphere (for example, Beerling and others 1995, Dubayah 1994), perhaps by using lichens and bryophytes as litmus tests of air quality.

The soil, however, is literally at our feet and figuratively at the hand of management, and there is much we can do to monitor and guide its health. It is ironic that soil health is so influenced by microbes but manifests its effect over vast geographic areas. Its complement of macro- and micro-organisms and their vast array of ecological functions can be quickly depleted under careless management yet may take so much longer to rejuvenate. And results of site-specific management

[2] Personal communication. 1996. P. Frenzen, Mount St. Helens National Volcanic Monument, USDA Forest Service, Washington.

activities that influence soil compaction, organic matter input, dispersal of mycorrhizae, vitality of seed banks, and persistence of microbiotic crusts, can be monitored with satellites. Maintaining ecological integrity will likely include heeding the lessons of soil by maintaining rich belowground biota with their full complement of ecological functions. In soil lies the vitality of future resources and ecosystems.

Managing for Ecological Integrity

We have identified locations within the basin assessment area that may invite attention of policy planners for meeting the three ecological goals for long-term integrity of terrestrial ecosystems at the broad scale. Terrestrial ecosystem integrity would likely benefit from further, similar assessments of our integrity components at finer resolutions for use in mid-scale planning and management activities.

Taken with assessments presented in Marcot and others (1997) and analyses in this report, we are encouraged that good opportunities still exist in the basin assessment area for meeting all three goals of terrestrial ecological integrity (that is, to maintain species viability, maintain long-term evolutionary potential of species, and manage for multiple ecological domains and evolutionary timeframes). To meet these goals, however, careful attention needs to be paid in the short term to those integrity components most at risk. These include threatened, endangered, rare, and potentially rare plants and animals; providing for species' habitats at the peripheries of their ranges and in disjunct population locations; providing for conditions to maintain hot spots and centers of concentration of plant and animal biodiversity and species rarity and endemism; and providing for habitats to maintain unique assemblages of plants and animals.

Other ecosystem integrity components of potential interest to successful ecosystem management include ensuring long-term productivity of soils and the belowground world; and attending to scarce and still-diminishing vegetation conditions, principally rare plant communities, native grasslands, native shrublands, and late seral subalpine multilayer forests. We expect, with careful salvage thinning and logging of many lower elevation forests, along with prudent reintroduction of fire into these ecosystems, that late seral ponderosa pine single-layer forests eventually can be encouraged to return. Additional components of ecological integrity and terrestrial species conservation that may be of interest to managers in the basin assessment area are presented by Marcot and others (1997).

An Uncertain Future for Humans and Terrestrial Ecosystems: Making Tough but Informed Choices

"The extirpation of populations and species of organisms exerts its primary impact on society through the impairment of ecosystem services" (Ehrlich 1988:24). Terrestrial ecosystems continue to surprise us. Like the intricate layering of Hindu temple architecture, on closer inspection they reveal new details and structures and new services to aid human societies. For example, pharmacological and economic benefits of maintaining the full expression of plant diversity have hardly been explored in terrestrial ecosystems of the basin assessment area, but other experiences (for example, Aylward and Fendt 1995) suggest a richness yet to be realized. Likewise, we have only begun to recognize the long-term value to human societies—both native and "naturalized"—in maintaining the full diversity and productivity of terrestrial systems, principally in soils and the belowground world. Again, experiences elsewhere (for example, papers in Bissonette and Krausman 1995) shed great light on how sustainable use of natural resources can be provided by better understanding ecosystem processes and living within those means—or suffering the consequences of unnecessary resource scarcity, economic disruption, and social uncertainty (Rathore 1995).

It is not entirely clear what future effects will come of increasing human occupation of the basin assessment area, particularly from increases in roads, recreation, and human habitations in the "urban-forest interface." Although, on average, human population density of the basin assessment area is low compared with other parts of the United States (McCool and others 1997), much of the assessment area is already roaded and under active land management for various goods and services (fig. 3). Rather certain scenarios of increasing human populations (McCool and

others 1997) and rather uncertain scenarios of regional climate change together could pose grave problems and challenges to managers for maintaining a strong semblance of native biota, ecological processes, and ecosystems. Assuredly, terrestrial ecosystems of the basin assessment area will continue to exist in one form or another. But, it is not clear how *ecosystem processes* such as nutrient cycling and frequency of wildfires, *structures* such as plant and animal communities and soil microbiota, and *services* such as soil productivity, nutrient storage, and interception of surface water runoff will be altered by increasing human presence and changing Federal land management policies and activities.

Human occupation of the land often serves to sharpen boundaries between managed and unmanaged landscapes. Examples of such boundaries are rural human habitations adjacent to National Forest lands; silviculturally managed timber stands adjacent to old-growth forests or research natural areas; and grazing pastureland or agricultural fields adjacent to native *Agropyron* or *Fescue* grasslands or sagebrush steppe. Managed systems are characterized by very large fluxes in exports of soil, nutrients, pesticides, and inorganic ions, along gradients steeper than naturally occur. These changes in rates ultimately affect soils, biota, and atmospheric exchange rates (Correll 1991). In soils, pH, Eh, ionic composition, nutrient and toxic metal concentrations, and organic matter pathways can be altered (Correll 1991). Such are the kinds of complex ecosystem changes that intensive natural resource management may induce and that managers may wish to better quantify.

Our aim in this report was to contribute to understanding the history and ecology of species, communities, and ecosystems of the basin assessment area. We hope we have helped build a basis for asking the right kinds of ecological questions, and a framework for beginning to answer those questions when conducting ecosystem planning and management. We also hope that the era of terrestrial ecosystem management on Federal public lands has evolved far beyond a simple focus on threatened and endangered species and big game, although these too are legitimate and essential parts of ecosystem planning. Many ecological relations among species affect diversity, productivity, and sustainability of ecosystems. Some relations are subject to change and can be threatened just as individual species or populations can, and thereby also warrant exquisite attention in research and management. We hope that the fruitless arguments of "species versus ecosystems" have been finally interred—as both are obviously essential and inextricable foci for understanding and for successfully managing ecosystems.

As well, an understanding of past and current situations—including variations in taxonomic groups ecological functions of species, redundancy of functions among species and communities, turnover (loss and gain) of species and taxa, and changes in climates and disturbance regimes—is fundamental to estimating the natural range of conditions, historic and present. Kay (1994) concludes that, historically, Native Americans commonly determined the structure of entire plant and animal communities by hunting and by setting fires (also see papers cited in Knowles and Knowles 1993), and that a current "natural regulation" approach to management does not recognize and thus probably would not replicate such historic conditions. He also pointed out that the historic reductions in number and distribution of beaver (*Castor canadensis*) throughout the West has had drastic effects on declining distribution of some wetland and upland ecological communities. Along with others, Kay asks the question, "What is natural?" It is a question we must answer within contexts of ecosystem policy goals, historic conditions, an understanding of prehistoric changes, background rates of extinction and origination of organisms at several taxonomic levels, the current biophysical template of the land, and even societal and political desires.

Ultimately, the range of natural conditions and ecosystem dynamics—if defined through a standard, rigorous, and repeatable process—spells out the history of the land and might provide an insight into what the land is capable of supporting in the future. Our choice as society is then to adhere to the dimensions of that envelope, or to force ecosystems into new, and usually more reduced, constitutions. At least, we hope, for terrestrial ecosystems of the basin assessment area, it will be a learned and informed decision.

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English Equivalents

1 kilometer (km) = 0.62 mile

1 meter (m) = 3.281 feet

1 hectare (ha) = 2.47 acres

Degrees Celsius (^oC) = 5/9(^oF-32),
where ^oF = degrees Fahrenheit

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Appendix 1

Categories of abundance and breeding or migration status of birds in the basin assessment area, as denoted in the species-environment relations database.

Abundance of birds:

A = Abundant
Within the right habitat and season, birds in this category would seem to be ubiquitous and numerous.

C = Common
Within the right habitat and season, birds in this category would be present.

U = Uncommon
Unlikely that birds in this category would be seen unless specifically searched for in the correct location and time. Populations are larger than those of rare birds but still not always seen when expected.

R = Rare
Seen every year but in very low numbers, usually less than 10 sightings per year. The Pacific loon, for example, is rare in Washington. Whereas the Pacific loon is out of its normal range when sighted inland, other species can be rare within their breeding range. For example, the black-backed woodpecker is a year-round resident of Montana. It breeds there but is at the edge of its range and is rarely seen because its populations are small.

I = Irregular
Usually seen in low numbers and not seen every year. An example is the Pacific loon along the Columbia River in Oregon; this species is seen in this location only in some years and always in low numbers. Another example is snowy owl, which is uncommon in the inland West when winters are harsh farther north, but which is absent in other years.

Breeding status of birds:

R = Resident
A bird species that breeds in the state and can be seen there year-round.

B = Breeding
A species that breeds in the state but winters elsewhere.

N = Nonbreeding summer resident
An unusual situation. Only a few bird species in the inland West fall into this category. One example is the blue jay, which does not breed anywhere in the inland West, but quite a few occur all summer in northwestern Wyoming.

W = Wintering
Bird species that spend the winter and breed elsewhere.

M = Migrants
Bird species present only in the spring and fall as they move between wintering and breeding areas.

Appendix 2

Lichen and bryophte species groups as bioindicators. Additional comments included here on species groups are from the Plant Task Group, SIT, Interior Columbia Basin Ecosystem Management Project (see Marcot and others 1997 for listings of specific species in each group).

Air Quality Indicators

Lichen Groups:

Bog lichens
Calcareous indicator lichens (a large group of species)
Calcareous steppe indicator lichens
Charred snag lichens (indicates recent fire)
Excess nitrogen indicator lichens
Fencepost lichens
Forage lichens
Fruticose tree lichens (only some of these species are old-growth indicators)
Leaf lichens (this is a large group of variable species)
Metal-rich indicator lichens
Moss and ditritus binders lichens
Nitrogen-fixing epiphytes lichens
Nitrogen-fixing rock lichens
Nitrogen-fixing soil lichens
Oceanic forage lichens
Oceanic leaf lichens
Oceanic log lichens
Oceanic rock lichens
Oceanic tree crust lichens
Pin lichens
Pioneer soil stabilizers lichens
Riparian lichens (indicators of high humidity)
Rock crusts lichens
Rock macro lichens (many species in this group)
Rotten log and tree base lichens (indicates ecological continuity)
Seepage lichens
Sheltered ledges and overhangs lichens
Soil lichens
Steppe soil crust lichens
Tree crusts lichens
Tundra forage lichens
Tundra rock lichens
Tundra sod builders (some species are calcareous indicators)
Urban pollution-tolerant lichens
Vagrant ground lichens

Bryophyte Groups:

Epiphytic bryophyte
Humus duff bryophyte
Peatlands bryophtye
Rock other bryophyte

Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

Alkaline (Carbonate) soil indicators

Lichen Groups:

Calcareous indicator lichens (large groups of species)
Calcareous steppe indicator lichens
Rock crusts lichens
Tundra sod builders (some species are calcareous indicators)
Vagrant ground lichens
Carex calcareous peatlands group (perennially saturated peat; most areas are open, but sedges on the edges of these peatlands are in partial shade)

Bryophyte Groups:

Aquatic submerged bryophyte
Peatlands bryophtye
Rock calcareous bryophyte
Rock wet bryophyte
Soil dry bryophyte
Soil wet bryophyte

High waterflow indicators

Lichen Groups:

Aquatic lichens (good indicators of water quality and flow levels)
Seepage lichens

Bryophyte Groups:

Aquatic submerged bryophyte
Rock wet bryophyte
Soil alkaline bryophyte

Low waterflow indicators

Lichen Groups:

Aquatic lichens (good indicators of water quality and flow levels)
Seepage lichens

Bryophyte Groups:

Aquatic submerged bryophyte
Rock wet bryophyte
Soil alkaline bryophyte

Grazing indicators-decreasers

Lichen Groups:

Calcareous steppe indicator lichens
Nitrogen-fixing soil lichens
Soil lichens
Steppe soil crust lichens

Tundra forage lichens
Tundra sod builders (some species are calcareous indicators)
Vagrant ground lichens
Carex sagebrush steppe dry group
Carex sagebrush steppe wetland riparian group (hot dry summers)

Grazing indicators-increasers

Lichen Group:

Pioneer soil stabilizers lichens

Bryophyte Groups:

Aquatic submerged bryophyte
Peatlands bryophtye
Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

High-nitrogen indicators

Lichen Groups:

Excess nitrogen indicator lichens
Fencepost lichens
Rock crusts lichens
Rock macrolichens (many species in this group)
Urban pollution-tolerant lichens

Bryophyte Groups:

Aquatic submerged bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

Metal-rich rock indicators

Lichen Groups:

Metal-rich indicator lichens
Rock crusts lichens

Bryophyte Groups:

Aquatic submerged bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

Old-growth forest indicators

Lichen Groups:

Calcareous steppe indicator lichens
Charred snag lichens (indicates recent fire)
Forage lichens
Fruticose tree lichens (only some of these species are old-growth indicators)
Moss and ditritus binders lichens
Nitrogen-fixing epiphytes lichens
Oceanic forage lichens
Oceanic leaf lichens
Oceanic log lichens
Oceanic tree crust lichens
Pin lichens
Riparian lichens (indicators of high humidity)
Rotten log and tree base lichens (indicates ecological continuity)
Steppe soil crust lichens
Tree crusts lichens

Bryophyte Groups:

Decayed wood bryophyte
Epiphytic bryophyte
Humus duff bryophyte
Peatlands bryophtye
Rock calcareous bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil dry bryophyte
Soil wet bryophyte

High soil temperature indicators

Bryophyte Groups:

Rock calcareous bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte
Low soil temperature indicators

Bryophyte Groups:

Peatlands bryophtye
Rock calcareous bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil dry bryophyte
Soil wet bryophyte
Tundra forage lichens
Tundra sod builders (some species are calcareous indicators)
Vagrant ground lichens

Carex calcareous peatlands group (perennially saturated peat; most areas are open but sedges on the edges of these peatlands are in partial shade)
Carex noncalcareous peatlands group (perennially saturated peat; most areas are open but sedges on the edges of these peatlands are in partial shade)

Coarse soil texture indicators

Bryophyte Groups:

Peatlands bryophtye
Rock calcareous bryophyte
Rock other bryophyte
Rock wet bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

Vascular Plant Groups:

Penstemon acuminatus group (sandy dunes and sandy areas near rivers)
Penstemon foothills to montane dry rocky group (rocky margins of old stream channels, scree, rock walls, outcrops, rocky roadcuts, and well drained areas; indicators of dry conditions)
Penstemon foothills to montane meadow group (indicators of changes in hydrologic regime)

Fine Soil Texture Indicators

Lichen Group:

Steppe soil crust lichens

Bryophyte Groups:

Peatlands bryophtye
Rock calcareous bryophyte
Soil alkaline bryophyte
Soil dry bryophyte
Soil wet bryophyte

Appendix 3

Rare or potentially rare vascular plant species as bioindicators. Note that this list includes only the rare or potentially rare species explicitly considered in this assessment. Other indicator plants that are not rare or potentially rare also can be identified. Additional comments included here on species are from the Plant Task Group, Science Integration Team, Interior Columbia Basin Ecosystem Management Project.

Alkaline (Carbonate) Soil Indicators:

Arabis fecunda
Astragalus paysonii
Botrychium ascendens
Botrychium lineare
Botrychium pedunculosum
Carex lenticularis var. *dolia*
Carex parryana ssp. *idahoa*
Chrysothamnus parryi ssp. *montanus*
Erigeron lackschewitzii
Lesquerella carinata var. *languida*
Lesquerella paysonii
Penstemon compactus
Physaria integrifolia var. *monticola*

High WaterFlow Indicators:

Artemisia ludoviciana ssp. *estesii*
Gratiola heterosepala
Grindelia howellii
Oxytropis campestris var. *columbiana*

Grazing Indicators - Decreasers (sensitive to grazing disturbances):

Astragalus sinuatus
Botrychium ascendens
Botrychium crenulatum
Carex parryana ssp. *idahoa*
Cymopterus acaulis var. *greeleyorum*
Eriogonum novonudum
Gratiola heterosepala
Lesquerella carinata var. *languida*
Lesquerella paysonii
Mimulus evanescens
Mimulus patulus
Oryzopsis contracta
Phacelia lutea var. *calva*
Phacelia lutea var. *mackenzeorum*
Silene spaldingii
Stanleya confertiflora
Thelypodium howellii ssp. *howellii*
Thelypodium howellii ssp. *spectabilis*

Metal-Rich Rock Indicators:

Haplopappus radiatus
Penstemon nikei

High Soil Temperature Indicators:

Astragalus diaphanus var. *diurnis*
Lesquerella carinata var. *languida*
Oryzopsis contracta

Low Soil Temperature Indicators:

Carex lenticularis var. *dolia*
Castilleja pilosa var. *steenensis*
Lesquerella humilis

Coarse Soil Texture Indicators:

Allium aaseae
Allium constrictum
Allium punctum
Allium robinsonii
Astragalus columbianus
Astragalus diaphanus var. *diaphanus*
Astragalus diaphanus var. *diurnis*
Astragalus mulfordiae
Astragalus pulsiferae var. *suksdorfii*
Astragalus sinuatus
Astragalus yoder-williamsii
Botrychium lunaria
Carex lenticularis var. *dolia*
Chrysothamnus parryi ssp. *montanus*
Cypripedium fasciculatum
Descurainia torulosa
Erigeron lackschewitzii
Hackelia cronquistii
Hackelia venusta
Lesquerella carinata var. *languida*
Lesquerella humilis
Lesquerella paysonii
Oxytropis campestris var. *columbiana*
Papaver pygmaeum
Penstemon glaucinus
Penstemon kingii
Penstemon lemhiensis (does well in disturbed subsoils, but seems to do best on developed, dark soils [mollisols] of gravelly loam texture)
Silene spaldingii
Stanleya confertiflora

Fine Soil Texture Indicators:

Aster jessicae
Astragalus sinuatus
Botrychium ascendens
Botrychium crenulatum
Botrychium lunaria
Botrychium paradoxum

Botrychium pedunculosum (successional relations unclear; species may prefer late seral grassland habitats, as well as early to mid successional forest habitat)
Calochortus longebarbatus var. *longebarbatus* (soils are colluvial)
Calochortus longebarbatus var. *peckii*
Calochortus nitidus
Camissonia pygmaea (plants at soil interface adjacent to talus)
Carex parryana ssp. *idahoa* (occurs in minerotrophic [rich] subalpine fens consisting of sedge peat; persistent, saturated emergent wetlands)
Chaenactis cusickii (ash deposits weathering to clays; few associates, almost always annuals; dry, barren sites)
Erigeron lackschewitzii (found exclusively on calcareous soil derived from dolomite; soils are cryptorthents of gravelly silt or loam)
Eriogonum novonudum
Grindelia howellii (plant occurs in many disturbed sites, but its native habitat may be upper drawdown zones of prairie ponds in the Ovando Valley)
Haplopappus liatriformis (does poorly in areas of significant grazing)
Howellia aquatilis (ponds surrounded by narrow ring of cottonwood and tall deciduous shrubs; populations fluctuate widely among years because of variation in precipitation; recent wild fluctuations of precipitation [1988-drought; 1993-wet; 1994-drought] have reduced populations)
Lepidium davisii (desert playas; hard gray-white clays; pH 6-7 at all playas; very few associated species; barren; roots deep in cracks)
Primula alcalina
Rorippa columbiae
Silene spaldingii (biscuits in biscuit-scabland on loess, alluvium, aeolian soils)
Trifolium douglasii (little known about this species)

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This report presents information on biogeography and broad-scale ecology (macroecology) of selected fungi, lichens, bryophytes, vascular plants, invertebrates, and vertebrates of the interior Columbia River basin and adjacent areas. Rare plants include many endemics associated with local conditions. Potential plant and invertebrate bioindicators are identified. Species ecological functions differ among communities and variously affect ecosystem diversity and productivity. Species of alpine and subalpine communities are identified that may be at risk from climate change. Maps of terrestrial ecological integrity are presented.

Keywords: Macroecology, paleoecology, ecological integrity, terrestrial communities, ecosystems, wildlife, fungi, lichens, bryophytes, vascular plants, invertebrates, arthropods, mollusks, amphibians, reptiles, birds, mammals, endemism, interior Columbia River basin, Klamath Basin, Great Basin.

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