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Status and trends of habitats of terrestrial vertebrates in relation to land management in the interior Columbia river basin

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Abstract

We analyzed effects of three land management alternatives on 31 terrestrial vertebrates of conservation concern within the interior Columbia river basin study area. The three alternatives were proposed in a Supplemental Draft Environmental Impact Statement (SDEIS) that was developed for lands in the study area administered by the US Department of Agriculture (USDA) Forest Service (FS) and US Department of Interior (USDA) Bureau of Land Management (BLM). To evaluate effects of these alternatives, we developed Bayesian belief network (BBN) models, which allowed empirical and hypothesized relations to be combined in probability-based projections of conditions. We used the BBN models to project abundance and distribution of habitat to support potential populations (population outcomes) for each species across the entire study area. Population outcomes were defined in five classes, referred to as outcomes A–E. Under outcome A, populations are abundant and well distributed, with little or no likelihood of extirpation. By contrast, populations under outcome E are scarce and patchy, with a high likelihood of local or regional extirpation. Outcomes B–D represent gradients of conditions between the extremes of classes A and E. Most species (65%, or 20 of 31) were associated with outcome A historically and with outcomes D or E currently (55%, or 17 of 31). Population outcomes projected 100 years into the future were similar for all three alternatives but substantially different from historical and current outcomes. For species dependent on old-forest conditions, population outcomes typically improved one outcome class — usually from E or D to D or C — from current to the future under the alternatives. By contrast, population outcomes for rangeland species generally did not improve under the alternatives, with most species remaining in outcomes C, D, or E. Our results suggest that all three management alternatives will substantially improve conditions for most forest-associated species but provide few improvements for rangeland-associated vertebrates. Continued displacement of native vegetation by exotic plants, as facilitated by a variety of human-associated disturbances, will be an on-going challenge to the improvement of future conditions for rangeland species. Published by Elsevier Science B.V.

Keywords: Bayesian modeling; Conservation; Ecosystem management; Models; Terrestrial vertebrates; Interior Columbia basin; Population viability; Wildlife habitat

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1. Introduction

The 58 million-ha interior Columbia river basin study area (hereafter referred to as Basin; see Fig. 1) encompasses a major portion of the western United States and supports highly diverse terrestrial communities, and associated plant and animal species. Terrestrial communities of the Basin are associated with a broad range of elevation and climatic zones, and compose the most varied ecosystems in which large-scale scientific assessments have been conducted (Hann et al., 1997). In testimony to this diversity, Marcot et al. (1997) identified 547 species of terrestrial vertebrates and 8078 species of vascular plants that occur in the Basin.

Habitats for many terrestrial vertebrates in the Basin have declined since settlement of the Basin by Europeans (Lehmkuhl et al., 1997; Marcot et al., 1997; Raphael et al., 1998; Wisdom et al., 2000). Specific changes in these habitats were documented by Wisdom et al. (2000) for 91 species of terrestrial vertebrates of conservation concern (Table 1). These 91 species were identified based on (1) rankings of the Nature Conservancy, (2) analysis of an earlier set of management alternatives proposed for federal lands within the Basin (Lehmkuhl et al., 1997), and (3) public concern as expressed through appeals of federal actions and the petition filed by the Natural Resources Defense Council with the Regional Forester of the Pacific Northwest Region, US Department of Agriculture Forest Service, on 30 March 1993.

The 91 species identified by Wisdom et al. (2000) were restricted to vertebrates for which habitats could be reliably estimated using a mapping unit (pixel size) of 1 km^2 and broad-scale methods of spatial analysis (Table 1). Vegetation data at this scale were compiled for the entire Basin (see Hann et al., 1997; Hemstrom et al., 2001). An additional 80 vertebrate species, mostly associated with riparian and wetland habitats, also were of conservation concern but were not analyzed by Wisdom et al. (2000) because their habitats could not be mapped at the 1 km^2 scale.

Species analyzed in Wisdom et al. (2000) were combined into 40 groups based on similarities in

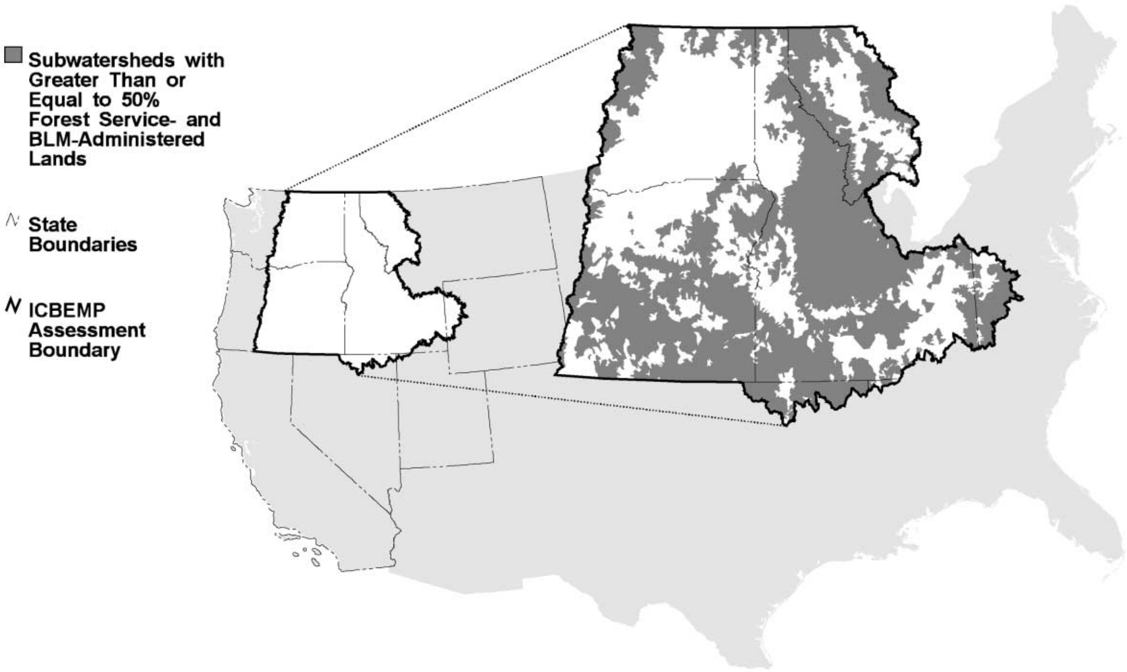

Fig. 1. The interior Columbia river basin study area. Results were summarized across all ownerships and for those subwatersheds with a land area of 50% or more administered by the USDA FS or the USDI BLM (FS–BLM).

Table 1
Ninety-one species of conservation concern (Wisdom et al., 2000) and the subset of 28 species (31 species-seasonal entries in bold letters) selected for this analysis

Common name	Scientific name	Terrestrial habitat family[a]
Lewis' woodpecker (migrant)	*Melanerpes lewis*	Low-elevation old forest (1)
White-headed woodpecker	*Picoides albolarvatus*	
White-breasted nuthatch	*Sitta carolinensis*	
Pygmy nuthatch	*S. pygmaea*	
Western gray squirrel	*Sciurus griseus*	
Northern goshawk (summer)	*Accipiter gentilis*	Broad-elevation old forest (2)
Blue grouse (winter)	*Dendrogapus obscurus*	
Flammulated owl	*Otus flammeolus*	
Great gray owl	*Strix nebulosa*	
Boreal owl	*Aegolius funereus*	
Vaux's swift	*Chaetura vauxi*	
Williamson's sapsucker	*Sphyrapicus thyroideus*	
Three-toed woodpecker	*P. tridactylus*	
Black-backed woodpecker	*P. arcticus*	
Pileated woodpecker	*Dryocopus pileatus*	
Olive-sided flycatcher	*Contopus cooperi*	
Hammond's flycatcher	*Empidonax hammondii*	
Chestnut-backed chickadee	*Poecile rufescens*	
Brown creeper	*Certhia americana*	
Winter wren	*Troglodytes troglodytes*	
Golden-crowned kinglet	*Regulus satrapa*	
Varied thrush	*Ixoreus naevius*	
White-winged crossbill	*Loxia leucoptera*	
Silver-haired bat	*Lasionycteris noctivagans*	
Hoary bat	*Lasiurus cinereus*	
Northern flying squirrel	*Glaucomys sabrinus*	
American marten	*Martes americana*	
Fisher	*M. pennanti*	
Woodland caribou	*Rangifer tarandus caribou*	
Blue grouse (summer)	*D. obscurus*	Forest mosaic (3)
Mountain quail (summer)	*Oreortyx pictus*	
Hermit warbler	*Dendroica occidentalis*	
Pygmy shrew	*Sorex hoyi*	
Wolverine	*Gulo gulo*	
Lynx	*Lynx canadensis*	
Lazuli bunting	*Passerina amoena*	Early-seral montane and lower montane (4)
Long-eared owl	*Asio otus*	Forest and range mosaic (5)
Gray wolf	*Canis lupus*	
Grizzly bear	*Ursus arctos*	
Mountain goat	*Oreamnos americanus*	
California bighorn sheep	*Ovis canadensis californiana*	
Rocky Mountain bighorn sheep (summer)	*O. c. canadensis*	
Rocky Mountain bighorn sheep (winter)	*O. c. canadensis*	
Sharptail snake	*Contia tenuis*	Forests, woodlands, and montane shrubs (6)
California mountain kingsnake	*Lampropeltis zonata*	
Northern goshawk (winter)	*A. gentilis*	
Rufous hummingbird	*Selasphorus rufus*	
Black-chinned hummingbird	*Archilochus alexandri*	
Broad-tailed hummingbird	*S. platycercus*	

Table 1 (*Continued*)

Common name	Scientific name	Terrestrial habitat family[a]
Pine siskin	*Carduelis pinus*	Forests, woodlands, and sagebrush (7)
Yuma myotis	*Myotis yumanensis*	
Long-eared myotis	*M. evotis*	
Fringed myotis	*M. thysanodes*	
Long-legged myotis	*M. volans*	
Western small-footed myotis	*M. ciliolabrum*	
Spotted bat	*Euderma maculatum*	
Pale western big-eared bat	*Corynorhinus townsendii pallescens*	
Pallid bat	*Antrozous pallidus*	
Western bluebird	*Sialia mexicana*	Rangeland, and early- and late-seral forest (8)
Ash-throated flycatcher	*Myiarchus cinerascens*	Woodland (9)
Bushtit	*Psaltriparus minimus*	
Mojave black-collared lizard	*Crotaphytus bicinctores*	Range mosaic (10)
Longnose leopard lizard	*Gambelia wislizenii*	
Striped whipsnake	*Masticophis taeniatus*	
Longnose snake	*Rhinocheilus lecontei*	
Ground snake	*Sonora semiannulata*	
Ferruginous hawk	*Buteo regalis*	
Burrowing owl	*Athene cunicularia*	
Short-eared owl	*A. flammeus*	
Vesper sparrow	*Pooecetes gramineus*	
Lark sparrow	*Chondestes grammacus*	
Western meadowlark	*Sturnella neglecta*	
Preble's shrew	*S. preblei*	
White-tailed antelope squirrel	*Ammospermophilus leucurus*	
Washington ground squirrel	*Spermophilus washingtoni*	
Wyoming ground squirrel	*S. elegans nevadensis*	
Uinta ground squirrel	*S. armatus*	
Pronghorn	*Antilocapra americana*	
Sage grouse (summer)	*Centrocercus urophasianus*	Sagebrush (11)
Sage grouse (winter)	*C. urophasianus*	
Sage thrasher	*Oreoscoptes montanus*	
Loggerhead shrike	*Lanius ludovicianus*	
Brewer's sparrow	*Spizella breweri*	
Black-throated sparrow	*Amphispiza bilineata*	
Sage sparrow	*A. belli*	
Lark bunting	*Calamospiza melanocorys*	
Pygmy rabbit	*Brachylagus idahoensis*	
Sagebrush vole	*Lemmiscus curtatus*	
Kit fox	*Vulpes macrotis*	
Columbian sharp-tailed grouse (summer)	*Tympanuchus phasianellus columbianus*	Grassland and open-canopy sagebrush (12)
Clay-colored sparrow	*S. pallida*	
Grasshopper sparrow	*Ammodramus savannarum*	
Idaho ground squirrel	*S. brunneus*	
Black rosy finch	*Leucosticte atrata*	None[b]
Gray-crowned rosy finch	*L. tephrocotis*	
Lewis' woodpecker (resident)	*M. lewis*	
Brown-headed cowbird	*Molothrus ater*	

[a] Terrestrial family number, as referred to in the text, follows the family name; see Wisdom et al. (2000) for further details about vegetation and elevational ranges associated with terrestrial families.

[b] These four species were not assigned to a family.

broad-scale habitat use, and 37 of these groups were further combined in 12 "families" (Table 1). Greatest declines in broad-scale habitat were projected for species that depend on either (1) low-elevation, old-forest habitats, (2) combinations of rangelands with early-seral or late-seral forests, or (3) native grasslands and open-canopy sagebrush (*Artemisia* spp.).

In this paper, we build on the results of Wisdom et al. (2000) to evaluate effects of three management alternatives proposed in a Supplement Draft Environmental Impact Statement (SDEIS) that was developed for lands administered by the US Department of Agriculture (USDA) Forest Service (FS) and US Department of Interior (USDI) Bureau of Land Management (BLM) in the Basin.

All three alternatives are designed to restore or maintain ecosystem health over the long term while providing predictable and sustainable levels of products and services, including fish, wildlife, and native plant communities. Alternative S1 continues practices currently in use within over 60 separate land management plans in the study area. Alternative S2 reduces short-term risk from management activities by requiring finer-scale analyses prior to such activities. Restoration of vegetation and characteristic succession, and disturbance patterns is prioritized for specific conditions (e.g., low elevation dry forest types) and specific subbasins (e.g., subbasins that have high risk to terrestrial and aquatic habitats). Protection is provided to specific watersheds for aquatic and terrestrial resources by conserving existing habitat. Alternative S3 provides for the social and economic needs of people while aggressively taking actions to reduce long-term risk to natural resources from human and natural disturbances. More subbasins are identified as priority for restoration in S3 than in S2; however, considerably less emphasis is placed on completing the finer-scale analyses prior to taking initial restorative actions. Protection is provided to specific watersheds for aquatic and terrestrial resources by avoiding short-term risk and conserving existing habitat (USDA and USDI, 2000).

We had three primary objectives for our analysis. The first was to demonstrate a new application of Bayesian belief network (BBN) models to evaluate conditions that affect species viability. For this evaluation, we assume a viable population is one that is likely to persist, well distributed throughout the species' range in the Basin. The second objective was to estimate effects of future land management and successional processes on habitat conditions for species whose viability might be at risk, particularly species whose abundance and distribution of habitats have declined substantially since settlement of the Basin by Europeans. The third objective was to provide FS and BLM managers with information on the efficacy of conservation actions proposed for these species and their habitats, such that future management actions might be refined for greater effectiveness.

2. Overview of methods

2.1. Species selected for analysis

Our analysis for the SDEIS focused on a subset of 28 species out of the 91 originally analyzed by Wisdom et al. (2000). This subset was selected within the context of the 12 families to represent the full array of species responses to conditions projected within the Basin. Analysis of effects of the SDEIS on vascular plants, and riparian- and wetland-dependent species was conducted through more generalized processes and is not reported here. In selecting 28 species (31 species-seasonal combinations, referred to hereafter as 31 species) for more detailed analysis, we applied the concept of focal species (Lambeck, 1997), the findings of Wisdom et al. (2000), and the structure of our own models. The intent was to select a set of species that represent the full array of species responses to conditions projected under the management alternatives. For this paper, we highlight results for three of these species — pygmy nuthatch (see Table 1 for scientific names of all vertebrates), sage grouse, and wolverine — to illustrate the more detailed findings projected for all 31 species.

Pygmy nuthatch is featured as an example of species dependent on low-elevation, old-forest habitats. The species is broadly distributed throughout the Basin, but has more restrictive habitat requirements than other similar species (Wisdom et al., 2000). Pygmy nuthatches are secondary cavity-nesters that use large-diameter snags, especially of ponderosa pine (*Pinus ponderosa*), for nesting (McEllin, 1979), and typically forage in live ponderosa pine (Bock, 1969).

Although Breeding Bird Survey data indicate stable population trends for this species in the Basin (Sauer et al., 1996), loss of old forests and associated structures in the Basin is of concern.

Sage grouse are included as an example of species dependent on shrub-steppe habitats. This species is closely associated with sagebrush-dominated sites, as well as herbaceous wetlands. Riparian vegetation is particularly important during the brood-rearing period (Wisdom et al., 2000). Within the Basin, the single largest loss among cover types from historical to the current period has been in big sagebrush (*A. tridentata*), primarily from conversion to agriculture (Hann et al., 1997). Populations of sage grouse within the Basin are markedly disjunct (Wisdom et al., 2000), and the species has declined throughout its range in western North America (Connelly and Braun, 1997).

Finally, wolverine is featured as an example of a wide-ranging carnivore, sensitive to human presence and activities (Copeland, 1996; Hornocker and Hash, 1981), and for which broad-scale conservation measures are appropriate. Although wolverine are habitat generalists, using many vegetation cover types and structural stages in the Basin (Wisdom et al., 2000), their denning requirements are more restrictive. Wolverine typically use high elevation cirques in relatively undisturbed sites for dens, which may occur in caves, on talus slopes, or in large, fallen trees (Copeland, 1996). Wolverine are also vulnerable to over-trapping (Banci, 1994), and may avoid areas where timber harvest has occurred (Hornocker and Hash, 1981).

2.2. *Source habitat projections*

Based on literature reviews and consultation with species experts, Wisdom et al. (2000) identified "source habitats" for 91 terrestrial species of conservation concern. Source habitats are those characteristics of macro-vegetation (cover types and structural stages) that contribute to stationary or positive population growth for a species within that species' distributional range. Source habitats contribute to source environments (Pulliam, 1988; Pulliam and Danielson, 1991), which represent the composite of all environmental conditions that result in stationary or positive population growth for a species in a specified area and time. The distinction between source habitats and source environments is important for understanding our evaluation and its limitations. For example, source habitats for a bird species during the breeding season would include those characteristics of vegetation that contribute to successful nesting and rearing of young, but would not include non-vegetative factors, such as the effects of pesticides on thinning of eggshells, which also affect production of young. Cover types and structural stages identified as source habitats were classified from dominant conditions at the scale of a 1-km^2 pixel.

Using outputs from landscape projection models (Hann et al., 1997; Hemstrom et al., 2001), we summarized total amount of source habitat at the subwatershed (drainages averaging 78 km^2) or watershed (larger drainages averaging 225 km^2) scales for the full suite of 91 species for historical, current, and projected future conditions under the three SDEIS alternatives. Historical conditions (ca. 1850–1890) represent estimates of vegetation conditions that existed during early settlement by Europeans, whereas current conditions (as classified from 1991 satellite imagery) reflect vegetation conditions during the last decade. Projected future conditions reflect estimates of vegetation cover 100 years into the future under management prescriptions and land allocations of each of the three SDEIS alternatives. Total amount of source habitat for any given species is best interpreted as an upper limit to the potential of an area to support that species. Additional considerations for quality of that habitat (e.g., its likelihood of providing more specific habitat elements) are necessary to refine estimates of potential capacity. We used the BBN modeling approach to make these refinements.

2.3. *Bayesian belief network models*

Evaluation of a previous set of alternatives, conducted by Lehmkuhl et al. (1997), was based upon an expert panel process. Teams of experts evaluated each alternative using information about trends in major habitat types and key features of each alternative. The panel approach was useful in providing a basis for evaluating implications of management on species viability and ranking the relative strength of each alternative, but the method had several shortcomings: (1) it was difficult to evaluate linkages between results and specific features of the alternatives, (2) replication of results was questionable because results were based on opinions of experts, (3) implications of changes in alternatives could not be evaluated without reconvening panels, and (4) results were not spatially explicit.

To overcome these limitations, we used a BBN model to assess relations between habitat conditions and proposed management direction under three SDEIS alternatives (see Marcot et al. (2001) for additional details about BBN models). The primary advantages of the BBN modeling approach were (1) the models provided an explicit representation of the linkages between features of an alternative and hypothesized response of a species, (2) models could be rerun with different alternatives, new assumptions, or revised features of alternatives, (3) model results included measures of uncertainty and sources of variation, and (4) model results were spatially explicit. We developed two spatially tiered BBN modeling approaches for our analysis.

2.3.1. Environmental index model

An "environmental index model" (Fig. 2A) was designed to characterize the quantity and quality of habitat and other environmental factors affecting populations of each species within either subwatersheds (for 27 species) or watersheds (for four species of wide-ranging carnivores). There are 7467 subwatersheds nested within 2562 watersheds in the assessment area. The primary components of the environmental index models included a measure of habitat density (source habitat as identified in Wisdom et al., 2000) within the subwatershed, specific environmental correlates important to the species (e.g., condition of large snags expressed as an average for each subwatershed), and proxies for those correlates that link each to a landscape variable (such as density of large snags and departure from the historical range of variability (HRV)). HRV departure, originally derived from Hann et al. (1997), is a composite measure of the level of deviation from the HRV, as measured by the degree of change in vegetative patch size and arrangement, change in vegetative structure and composition, and change in large-scale disturbance regimes (due to changes in frequency and intensity of wildfire events, and insect and disease outbreaks). Hemstrom et al. (2000) further described the landscape variables used as proxies for environmental correlates in our environmental index models.

Within the distributional range of each species, we summarized the amount of a species' source habitat within each subwatershed into three classes: *zero*, *low*, and *high* (node AA, Fig. 2A). *Zero* indicated a subwatershed within the species' range that contained no source habitat. For subwatersheds containing source habitat, we computed the median percentage of habitat for that species from the historical projection. Any subwatershed with median or greater percentage was classified as *high* and assigned a numeric value of 2.0; any subwatershed with a percentage greater than zero but less than the median was classified as *low* and given a numeric value of 1.0. We used the same historical median to classify subwatersheds under current and future conditions. The environmental correlates interact with habitat density to yield an adjusted habitat density (node DD, Fig. 2A).

Finally, other nodes were added to account for environmental factors that directly influence individuals in a population independent of habitat (such as trapping or harassment of individuals associated with presence of roads), yielding a final environmental index (node EE, Fig. 2A). For the three species highlighted as case examples for this paper, proxies for environmental variables (see Hemstrom et al., 2000) included trend in large snag density (pygmy nuthatch), HRV departure (pygmy nuthatch, sage grouse), grazing effects departure (sage grouse), human population density (sage grouse and wolverine), and road density class (sage grouse and wolverine). For pygmy nuthatch, we used the proxy of trend in large snag density to index the abundance of large snags, and used HRV departure to index the shade-intolerant tree species desired as snags. For wolverine, we used the proxies of human population density and road density class to index the negative effects of human disturbance on denning habitats. For sage grouse, we used the proxy of HRV departure to index the degree to which exotic plants displaced native habitat, and the proxy of grazing effects departure to index the degree to which composition and structure of existing native habitat was negatively altered.

Interactions of all input factors to the environmental index model (all model nodes leading to node EE) were parameterized to yield probabilities for each of three states at node EE: zero, low, and high (displayed as percentages between 0 and 100, node EE, Fig. 2A).

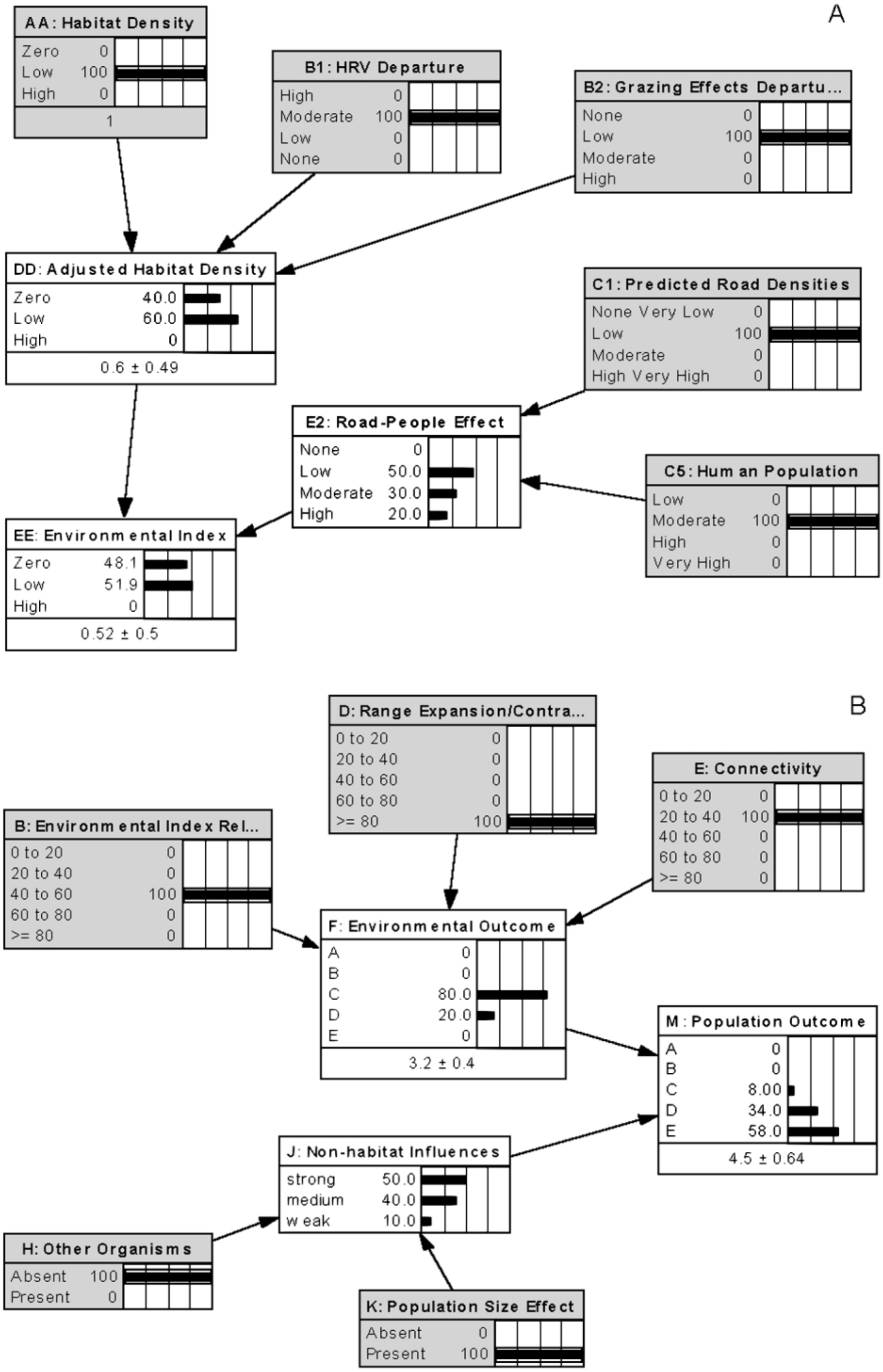

Fig. 2. Schematic of an example environmental index BBN model (sage grouse) (A) and the population outcome model (B).

These interactions were coded as conditional probabilities linking each state of node EE with all combinations of each state of each node that influences node EE (see Marcot et al. (2001) for details of model construction and parameterization). We used the model to calculate an expected value for node EE, estimated from the average of the numerical values of each of the three states weighted by the probability of each state. The expected value could range from 0.0 to 2.0 (node EE, Fig. 2A). For mapping purposes, we expressed output for node EE in three categories: high environmental index, defined as expected values >1; low, values ≤ 1 but >0; zero, values of 0 (see Fig. 3 for example).

We summarized results of the environmental index model in two ways to reflect land ownership patterns. First, we computed results across all ownerships throughout the Basin. Second, we identified each subwatershed with a land area of 50% or more administered by FS or BLM (hereafter referred to as FS–BLM or federal lands; see Fig. 1) and computed results for these subwatersheds as an indicator of FS–BLM conditions. The area within these federally administered subwatersheds represents 53% of the total land base, and 88% of the FS–BLM land base in the Basin. Comparisons between pixel-based estimates of habitat on FS–BLM lands versus estimates from subwatersheds with $\geq 50\%$ FS–BLM lands suggest that our method of summarizing conditions for subwatersheds dominated by FS–BLM ownership provided an accurate index of conditions on actual FS–BLM lands.

2.3.2. Population outcome model

We developed a population outcome model to project the Basin-wide distribution and abundance of each species and its environment for each time point (i.e., historical or current) and alternative (Fig. 2B). The population outcome model has two outputs. The first output (node F, Fig. 2B), referred to as an environmental outcome, is a large-scale index of the potential capability of the environment to support an abundant and well-distributed population, using data summarized from the environmental index model. Notably, environmental outcomes do not predict population occurrence, size, density, or other

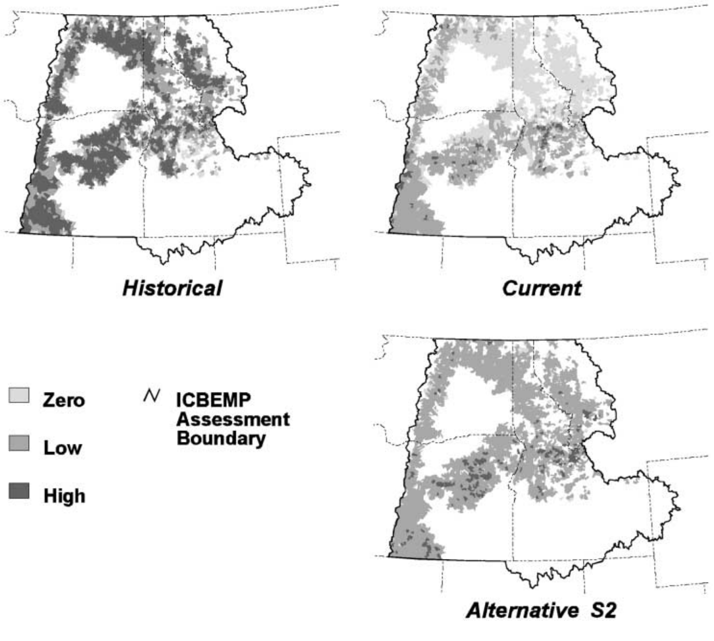

Fig. 3. Environmental index for pygmy nuthatch at historical, current, and 100-year (alternative S2) time points. Values ranged from 0 to 2; those >1 were mapped as *high* and those >0 but ≤ 1 as *low*.

demographic characteristics. We defined environmental outcomes as follows:

1. *Outcome A*. Suitable environments are broadly distributed and of high abundance across the historical range of the species. The combination of distribution and abundance of environmental conditions provides opportunity for continuous or nearly continuous intra-specific interactions for the species.
2. *Outcome B*. Suitable environments are either broadly distributed or of high abundance across the historical range of the species, but gaps exist where suitable environments are absent or only present in low abundance. However, the disjunct areas of suitable environments are typically large enough and close enough to permit dispersal among subpopulations and potentially to allow the species to interact as a metapopulation across its historical range.
3. *Outcome C*. Suitable environments are distributed frequently as patches and/or exist at low abundance. Gaps where suitable environments are either absent, or present in low abundance, are large enough that some subpopulations are isolated, limiting opportunity for species interactions. Subpopulations in most of the species range have the opportunity to interact as a metapopulation, but some subpopulations are so disjunct or of such low density that they are essentially isolated from other populations. For species for which this is not the historical condition, this isolation may result in reduction in overall species range from the historical projection.
4. *Outcome D*. Suitable environments are frequently isolated and/or exist at very low abundance. While some of the subpopulations associated with these environments may be self-sustaining, opportunity for population interactions among many of the suitable environmental patches is limited. For species for which this is not the historical condition, this isolation may result in reduction in overall species range from the historical projection.
5. *Outcome E*. Suitable environments are highly isolated and exist at very low abundance, with little or no possibility of population interactions among suitable environmental patches, resulting in strong potential for extirpations within many of the patches, and little likelihood of recolonization of such patches. Overall species range has likely been reduced from the historical projection, except for some rare, local endemics that may have persisted in this condition since the historical period.

The second output (node M, Fig. 2B), referred to as a population outcome, was generated from the combination of environmental outcomes (node F, Fig. 2B) and further adjustments that account for other influences, particularly non-habitat influences, that have wide-ranging effects on a population (node J, Fig. 2B). Population outcomes reflect the availability of habitat on both federal and non-federal lands, and environmental conditions within the planning area, as well as other influences on the species population that are not accounted for in the modeling of environmental outcomes. Examples of these other influences include spatially uniform, pervasive effects of interspecific interactions such as disease and predation, hunting, trapping, illegal taking, pesticide effects, air pollution effects, and low population size. In particular, low population size (node K, Fig. 2B), which may be brought about by Allee effects or other factors that cause populations to be much smaller than the environment might otherwise support, was the primary additional factor in the projection of population outcomes.

Definitions of population outcomes were nearly identical to those of environmental outcomes, with the same five outcome classes of A–E. Population outcomes, however, were expressed in terms of potential abundance and distribution of populations, in contrast to the characterization of abundance and distribution of suitable environments that were defined under the environmental outcomes. Notably, the classes of A–E for both the environmental and population outcomes are similar to the classes defined by Lehmkuhl et al. (1997) to evaluate earlier management alternatives developed for the Basin.

Projection of environmental and population outcomes was based in part on a summarization of all subwatershed-level environmental index values that were generated from each species' environmental index model. The population outcome model had three primary inputs from the environmental index model: (1) habitat capacity, (2) range extent, and (3) habitat connectivity.

Habitat capacity (node B, Fig. 2B) was calculated as an average of all environmental index values taken across all subwatersheds within the species range, weighted by the area of each subwatershed. This weighted average was then scaled to the historical average and expressed as a percentage, yielding a value ranging from 0 to >100. We assumed that habitat capacity is related to total population in the sense that a larger value indicates a larger potential population (as the index approaches 100, a species' potential population approaches its historical size; a value >100 indicates a potential population that exceeds the historical projection).

Range extent (node D, Fig. 2B), indicating expansion or contraction of source habitat within a species' range, was calculated as source habitat extent at any time point or alternative relative to historical amount of habitat. To calculate range extent, we summed the total area of all subwatersheds within a species' range that exceeded a threshold value of the environmental index for each time point and alternative. A value less than or equal to the threshold was assumed to indicate non-habitat, whereas a value above the threshold was assumed to indicate suitable habitat in the subwatershed. For most species, the threshold value was 0. For grizzly bear, Columbian sharp-tailed grouse, grasshopper sparrow, short-eared owl, and sage grouse, the threshold was 0.1; for Rocky Mountain bighorn sheep this threshold was 0.2. These non-zero thresholds were established because of the preponderance of environmental index scores slightly >0 for these species; we concluded that elimination of these areas with very low values from the calculation of range extent was ecologically equivalent to using the threshold of 0 for other species. The summed area, for any time point or alternative, relative to the summed area historically, yielded a value that could range from 0 to >100. Values <100 indicated range contraction; values >100 indicated range expansion.

Habitat connectivity (node E, Fig. 2B) was a measure of the degree to which patches of habitat fall within the dispersal capability of each species. Habitat connectivity was computed using the same threshold values that were used to calculate range extent. To compute connectivity, we used existing information to characterize the dispersal capability of each species, expressed as the distance over which 50% of dispersing juveniles could successfully traverse. For each species, we mapped all subwatersheds with environmental index values that exceeded the species' threshold, and defined patches by grouping all adjacent subwatersheds that met the threshold rule. We then extended a buffer out from each patch, using a buffer width equal to half the species' dispersal distance. Any patches that overlapped after applying this buffer were merged into patch clusters. The connectivity index was calculated as a weighted average of these cluster areas. The result was expressed as a percentage; values ranged from 0 to 100. A value of 100 indicates that all habitat is connected; smaller values indicate the degree to which patches are isolated.

Each of the three primary input variables of habitat capacity, range extent, and habitat connectivity was summarized into five levels or states (0 to <20, ≥20 to <40, ≥40 to <60, ≥60 to <80, and ≥80). A conditional probability table was then constructed to assign likelihoods of each of the five classes of environmental outcomes for each potential combination of states from the three primary input variables (see Marcot et al. (2001) for additional details). Finally, an additional probability table was constructed that linked the environmental outcome node with that for non-habitat influences (node J, Fig. 2B) to project likelihoods of each of the five classes of population outcomes. The environmental and population outcome classes of A–E were thus expressed as likelihoods of each class occurring at any time point or alternative.

The population outcome model also generates an expected value (weighted mean) for each species and time point, which is the sum of the products of the likelihoods of each outcome class and its numerical value. We assigned outcome A, a numerical value of 1.0 and B, C, D, and E values of 2.0, 3.0, 4.0 and 5.0, respectively. After calculation of the expected value, we reassigned outcomes using ranges of these expected values for each species and time point as follows: 1.0–1.5 for outcome A, >1.5–2.5 for B, >2.5–3.5 for C, >3.5–4.5 for D, and >4.5 for E.

We computed environmental outcomes for all Basin lands and also for FS–BLM lands (using subwatersheds with land area of 50% or more administered by FS or BLM as described above). For the FS–BLM analysis, we used connectivity (node E) from the all lands analysis to avoid problems with artificial fragmentation resulting from ownership pattern. All other nodes were computed within FS–BLM subwatersheds. We did not compute population outcomes from FS–BLM lands because that outcome was meant to convey information about all influences on potential populations including influences of all lands. Moreover, due to the artificial nature of property boundaries in contrast to animal use of the entire landscape, our projections of population outcome were not designed to provide meaningful results for FS–BLM lands by themselves.

2.4. Identifying factors of most influence on model results

We identified model variables (key factors) that contributed most strongly to low environmental indices and low population outcomes for each species by examining subwatersheds having lowest environmental index values, and determining the dominant states of each input variable to the environmental index model within these subwatersheds. A similar examination was made of the dominant states of each input variable to the population outcome model in relation to projected environmental and population outcomes (results of this analysis for all 31 species are available from the authors). For brevity, key factors are identified here for the three example species. Key factors identified for each of the 31 species can be used to design modifications in management direction that presumably would improve conditions for each species.

2.5. Key modeling assumptions

Our evaluation required several assumptions. Many assumptions were carried forward from work of the landscape team (see Hemstrom et al., 2001), upon which much of our analysis was based. Key assumptions include:

- Projections of landscape conditions for each time point and alternative (Hemstrom et al., 2001), which are the foundation for our BBN models, are accurate to the scales and levels described by Hann et al. (1997) and Wisdom et al. (2000).
- Landscape variables and their interactions, as used in our BBN models, accurately reflect empirical and hypothesized relations of each species with its environment; these relations can be validated through large-scale research.
- Environmental variables considered important to a species' requirements, but not available from landscape projections, are indexed accurately by associated proxy variables that were estimated as part of landscape projections.
- The large set of assumptions unique to each species' BBN model accurately reflects the views of species experts regarding species' requirements, and accurately considers the management direction of each of the three SDEIS alternatives. A complete set of assumptions, and environmental and proxy variables associated with the 31 species' BBN models is available from the authors.

3. Results

3.1. Habitat and environmental index values on all lands

Amounts of source habitat for most of the 28 species evaluated declined from historical to current, often by as much as 30–50%. For old-forest species, amounts of source habitat increased from the current period to the future under all SDEIS alternatives; quantities of source habitat typically increased to at least 80% of historical amounts. By contrast, amounts of source habitat for rangeland species declined from historical to current periods, and were projected to be stable or declining under projections for the alternatives. For example, amount of source habitat for species dependent on grassland and open-canopy sagebrush (family 12) declined by 50–69% from historical to current periods, and declined another 2–9% from the current period to the future under all alternatives.

The number of subwatersheds with a high environmental index value (>1, on a scale from 0 to 2) was generally greater under alternative S2 (17 species) than under S1 (nine species) or S3 (two species). However, mean environmental index scores were similar among alternatives, suggesting that although alternative S2 may lead to local improvements within particular subwatersheds, overall improvements at the scale of the entire Basin were not large enough to cause differences among alternatives in outcome class.

3.2. Population outcomes on all lands

Population outcomes for nearly all species (90%) declined from historical to current periods (Appendix A). Most species (65%, or 20 of 31) were associated with outcome A historically, whereas 55% (17 of 31) were associated with outcomes D or E currently.

Population outcomes were similar among all three alternatives (Appendix A) but often were substantially different from outcomes that were projected for historical and current periods. Specifically, population outcomes for species dependent on old-forest conditions typically improved one outcome class — usually from E or D to D or C — from current to the future under the alternatives. By contrast, population outcomes for rangeland species (species in families 10, 11, and 12, Appendix A) generally did not improve under the alternatives, with most species remaining in outcomes C, D, or E.

Under current conditions, rangeland species also had lower expected values for population outcome than did old-forest species, and this disparity increased into the future under all alternatives (Appendix A). Under the alternatives, expected values of population outcomes increased for about 50% of species (mostly old-forest species), with alternative S2 somewhat better than S1 and S3. These improvements resulted in outcome C becoming the dominant class in the future. Only 6% (two of 31) of the species had expected values of population outcomes that declined under the alternatives relative to current. Moreover, no species had a population outcome that declined a full class under the alternatives relative to current.

3.3. Habitat and environmental index values on FS–BLM lands

Federal lands compose the majority or near-majority of the land base for most species in our analysis. For 30 of the 31 species, federally administered lands compose an average of 56% of the land base (range 21–93%) within these species' ranges. Consequently, management of federal lands can have substantial effect on overall conditions for most species throughout their range in the Basin. The one exception is the Washington ground squirrel, which had <2% of its range within FS–BLM lands, thus limiting the influence of federal management on this species' habitat.

For all species, source habitats on federal lands showed patterns similar to those from the Basin as a whole, with declines from historical to current, and improvements for old-forest species under the alternatives. As for all lands, the number of subwatersheds with high values for environmental index was somewhat greater under alternative S2 than under S1 or S3. Environmental index scores across all 31 species were approximately 10–15% higher on FS–BLM lands versus all Basin lands under all alternatives. These results suggest that population outcomes would be more favorable for these species if conditions on FS–BLM lands existed on all lands in the Basin.

3.4. Environmental outcomes on FS–BLM lands

Environmental outcomes (node F) for species on federal lands were similar to those for all lands in the historical projection (Appendix A). Under current conditions, however, environmental outcomes were better than those on all lands for 11 of 31 species, including eight rangeland species. Under future conditions, environmental outcomes were better under at least one alternative for 13 species on federal lands versus all lands (Appendix A).

Historically, environmental outcomes for most species on federal lands were in outcome A (21 of 31 species); only two species achieved outcome A under the current period. Six species were projected to achieve outcome A under alternative S1 and seven species did so under alternatives S2 and S3 (Appendix A). Environmental outcomes on FS–BLM lands under current conditions and all alternatives were dominated by outcome C (35–45% of species).

3.5. Model projections for three example species

Detailed results for pygmy nuthatch, wolverine, and sage grouse are presented below as case examples. As with the summary of results presented for all species, results for the three example species are reported for both the environmental index model and the population outcome model. For simplicity, results for alternative S2 are often highlighted for the case examples, due to similarities of results among all three alternatives.

3.5.1. Pygmy nuthatch

Environmental index variables for pygmy nuthatch included source habitat, HRV departure, and trends in large snag density. Environmental index values for this species declined substantially from historical to current periods (Fig. 3). This decline was associated with a 68% reduction in amount of source habitats from historical levels, coupled with 73% of subwatersheds estimated to have declining snag densities currently. The decline in source habitat was particularly notable in the northern portions of the species range, and 58% of all subwatersheds were estimated to have undergone a complete loss of habitat from historical to current periods (Fig. 3).

By contrast, projections of the environmental index values improved substantially under alternative S2, largely due to a substantial projected increase in amount of source habitat. Specifically, amount of source habitat was projected to improve under all alternatives to about 62–67% of historical abundance. In addition, trends in snag density improved slightly under the alternatives relative to the current period, but the majority of subwatersheds still had declining trends under all three alternatives.

Number of subwatersheds with a low environmental index also more than doubled under all alternatives from the current period for pygmy nuthatch (Fig. 3). This increase was due primarily to recovery of source habitat in subwatersheds that had zero value currently. Specifically, 57% of the subwatersheds had zero value currently but only 6% of the subwatersheds had zero value under the alternatives.

Population outcome for pygmy nuthatch declined strongly since the historical period, with an outcome of D projected for the current period, and C projected for all alternatives (Appendix A, Fig. 4A). The environmental outcome (node F) on FS–BLM lands was slightly better than the all lands environmental outcome under all alternatives (Appendix A).

3.5.2. Wolverine

Environmental index variables for the wolverine model included source habitat, road density, and human population density. There was a slight increase (19%) in amount of source habitat for this species from historical to current periods; this increase persisted under all alternatives. Wolverines are habitat generalists, and source habitats identified for the species occur in nearly every structural stage of alpine tundra, subalpine forest, and montane forest in the Basin (Wisdom et al., 2000). Increases in all seral stages (early, mid, and late) of montane forest, though variable across the Basin, most influenced increases in source habitats from historical to current within the range of wolverine (Wisdom et al., 2000).

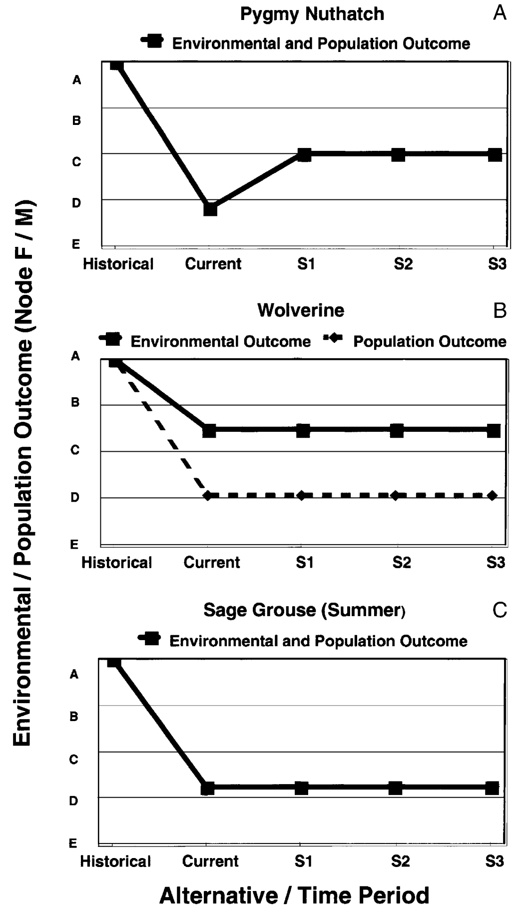

Fig. 4. Projected environmental outcomes (node F) and population outcomes (node M) across all Basin lands for pygmy nuthatch (A), wolverine (B), and sage grouse (C) at historical, current, and 100-year time points (alternatives S1, S2, S3; see text for definitions of outcome classes).

The number of watersheds with low environmental index scores, however, increased by 84% from historical to current periods, and remained at that level under all alternatives, reflecting a decrease in the number of both zero and high scores during this period (Fig. 5).

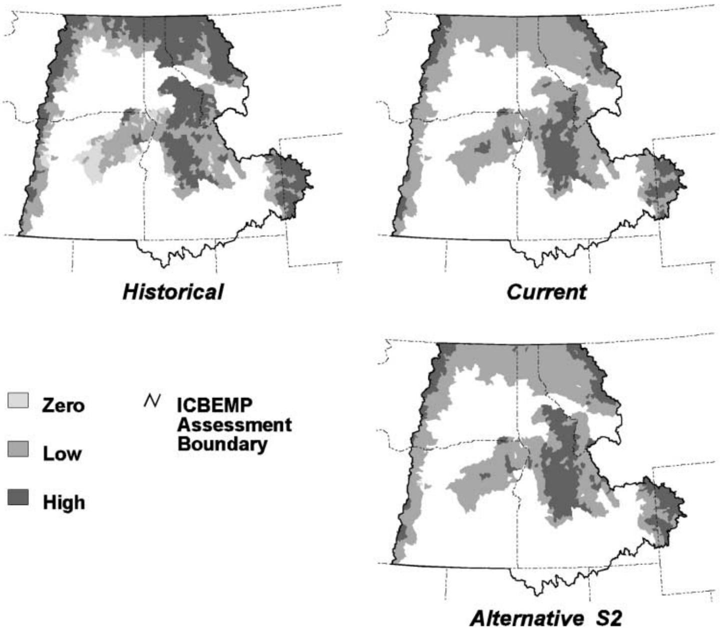

Fig. 5. Environmental index for wolverine at historical, current, and 100-year (alternative S2) time points. Values ranged from 0 to 2; those >1 were mapped as *high* and those >0 but ≤1 as *low*.

The number of watersheds with high environmental index scores decreased by 50% from historical to current periods and recovered somewhat under all alternatives, though not to historical levels (Fig. 5). The distribution of environmental index scores (i.e., relative proportions of high, low, and zero) was nearly identical among alternatives. Finally, the number of watersheds characterized by moderate to high/very high road density increased substantially from historical to current (from 0% historically to 62% currently), and declined slightly from current to 59% under each alternative.

Population outcomes for wolverine dropped from outcome A historically to D currently and under all alternatives (Appendix A, Fig. 4B). The decline in population outcome from historical conditions was due to a nearly 50% decline in habitat capacity scores (node B declined from 100% historically to 54–58% for current and all alternatives), as well as the population size effect (Appendix A).

Environmental outcomes (node F) for FS–BLM lands were similar to those for all Basin lands historically and currently (Appendix A). However, environmental outcomes under the alternatives were better on federal lands versus all lands (outcome B for federal lands versus C for all Basin lands).

3.5.3. Sage grouse

Environmental index variables for sage grouse included source habitat, HRV departure, grazing effects departure, road density, and human population density. Source habitats declined more than 25% from historical and were projected to continue to decline substantially under all alternatives. Number of subwatersheds with a low environmental index also increased by >60% under all alternatives compared with the current number, paralleling a >70% decline in the number of subwatersheds with a high index (Fig. 6). In addition, the number of subwatersheds with a high environmental index was about 15% greater under alternatives S2 and S3 compared with S1, though these subwatersheds represented less than 10% (or 17% of FS–BLM lands) of the subwatersheds overall (Fig. 6).

Population outcome for sage grouse declined substantially from historical levels; current and future outcomes under all alternatives were a D (Appendix A, Fig. 4C). However, the environmental outcome

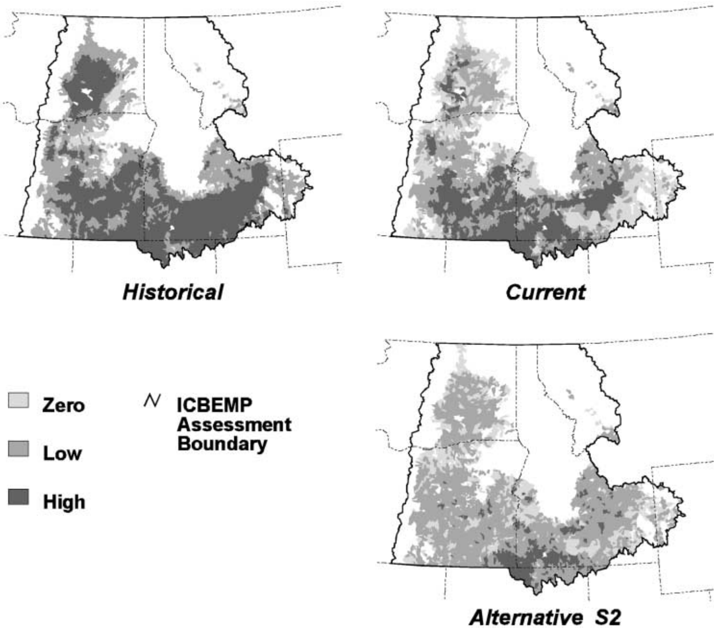

Fig. 6. Environmental index for sage grouse at historical, current, and 100-year (alternative S2) time points. Values ranged from 0 to 2; those >1 were mapped as *high* and those >0 but ≤1 as *low*.

on FS–BLM lands was one class higher currently (C versus D), and was slightly better under the alternatives, compared to the environmental outcomes on all lands (Appendix A).

4. Discussion and interpretation

4.1. Interpretation of modeling results

Our analysis relied on models that represent our probability-based estimate of the response of each species to changing environmental conditions. We recognize that models are not reality, but rather are an interpretation of reality and reflect our assumptions, and current understanding of wildlife habitat relationships. We used both empirical data and professional judgment to build models that project our best understanding of how the system operates at the broad-scale and the interactions among system components. Uncertainty is inherent in the modeling process and creates an explicit opportunity for validation testing and sensitivity analysis. We strongly recommend that comprehensive, broad-scale research be initiated to validate our species model projections for the current period. Validation research is the most appropriate and efficient means of addressing sources of modeling uncertainty and increasing our knowledge about species response to environmental conditions. Important sources of modeling uncertainty are described below.

1. Estimates of amount of cover types and structural stages were derived from landscape projections modeled for the Basin (see Hann et al., 1997; Hemstrom et al., 2001) and are subject to error. Error rates generally decline with increasing size of area over which the estimates are made (Hann et al., 1997; Wisdom et al., 2000).
2. Projected effects of the alternatives on specific environmental attributes (such as trend in snag or log density) are also subject to estimation errors (Hemstrom et al., 2000). Such errors can be propagated with the inclusion of a large number of environmental parameters in a given model.
3. Most effects of forest and range management were estimated by using landscape proxies to index the environmental attributes of interest. These landscape proxies presumably are correlated with the attributes, but the strength of these correlations is untested. Moreover, it is possible that many local

changes in landscape conditions that may occur under each alternative are not fully reflected in the landscape proxies.

4. The BBN models were built using conditional probabilities linking states of each attribute to responses of wildlife populations. These probabilities were assigned using professional judgment and expert opinion. Uncertainty is inherent in these models and probabilities.
5. All BBN models were peer-reviewed (see Acknowledgments). Our BBN models were built using what we and our peer reviewers believed were the most important attributes affecting each species, based on empirical data available for each species. It is possible that other, as yet undescribed, factors may also influence a given species. To the extent that important factors may have been missed, models can give misleading results.
6. Our categories of amounts of source habitat (zero, low, high) are a measure of habitat density and not an absolute measure of likelihood of species occurrence or persistence for a given area.

Finally, our models were meant to portray relative quality of environmental conditions affecting populations over time and among alternatives. These models should not be used to compute the actual density or population size of a species at any particular location. In this context, it is important to note that our environmental index model estimates relative densities, not absolute densities. Similarly, our population outcome scale is a relative measure of the amount and distribution of suitable environments and associated potential populations. Population outcomes are not a direct measure of population viability.

The original selection of species of concern for analysis by Wisdom et al. (2000) was based on several criteria, as described in Section 1. Because their analyses were intended for use in broad-scale, ecosystem-based management, they included species for which there might be even moderate concern, not just those species critically in need of attention. Use of an inclusive rather than an exclusive list of species assured that all associated habitats requiring restoration were addressed.

Results of our analyses of effects of the SDEIS alternatives indicate that, for some of these species (e.g., blue grouse, northern goshawk), future conditions are equivalent to, or only slightly worse, than historical or current conditions (Appendix A). This seemingly optimistic outlook does not warrant elimination of these species from further monitoring. Given the broad-scale nature of our models, we may have been unable to capture fine-scale features on which these species rely.

A striking result of our analysis is that for 25 of the 31 species (81%), environmental outcome classes for federal lands did not differ among alternatives. One possibility is that our models were not sensitive enough to detect differences in species responses among alternatives that are in fact very different. This explanation seems unlikely because the models detected differences from historical to present and from present to future. A more likely explanation is that the alternatives are fundamentally very similar in design, at least in terms of how management prescriptions play out in the expression of vegetation conditions that are important for the set of species we evaluated. The prevailing environmental and population outcome was C for most species, and often this was an improvement over current conditions. Biologically, an outcome of C still represents a risky condition for some species. Whether this outcome is acceptable is a management and public policy decision. However, our analysis has demonstrated that only marginal improvements are likely to be realized, especially for species associated with rangelands.

4.2. *Management influence on model results*

By examining responses of species to variability in input states of nodes in our two models (environmental index and population outcome), we identified model variables (key factors) that appear to have contributed most strongly to projected environmental indices and population outcomes. Results of this work could be used to design modifications in management direction that presumably would improve conditions for these species. For the three species highlighted in this paper, population outcomes of C (pygmy nuthatch) or D (wolverine and sage grouse) were projected under all alternatives. Consequently, opportunities exist to improve outcomes for these species through management actions. FS–BLM ownership represents a significant portion of all three species' ranges; thus, FS–BLM management could substantially influence overall environmental conditions for each species.

Key factors on FS–BLM subwatersheds are identified below, based on our analysis described under "Identifying Factors of Most Influence on Model Results". Factors identified for each species represent those that presumably would yield the greatest increase in environmental index values and population outcome if input states for such factors were improved through an adjustment in management actions.

4.2.1. Pygmy nuthatch

For pygmy nuthatch, low recruitment of large snags composed of shade-intolerant tree species, such as ponderosa pine, western larch (*Larix occidentalis*), and western white pine (*P. monticola*), as indexed by moderate and high HRV departure, was the key factor contributing to low environmental index values and low population outcomes. Any actions that would increase recruitment of large snags from shade-intolerant tree species would benefit this species.

4.2.2. Wolverine

High negative effects of human disturbance, as indexed by moderate to high/very high road density and moderate to high human population density, was the key factor that contributed to low environmental index values, and to low environmental outcomes, on all lands as well as FS–BLM lands, both currently and under all SDEIS alternatives. Small population size of wolverine further contributed to low population outcomes under all alternatives. For this species, retention of existing areas of very low road density appears to be essential. Management actions that further reduce road density or access by people would benefit this species by expanding the extent of habitat with little human disturbance, especially in high elevation cirques used for denning.

4.2.3. Sage grouse

The factors primarily responsible for the low environmental index and low population outcomes for sage grouse were the absence or low abundance of source habitats; moderate to high HRV departure (indexing a high degree of native vegetation displacement by exotic vegetation), combined with moderate to high grazing effects departure (indexing reduced biomass, cover, and height, and altered composition of native vegetation), and moderate to very high road density (indexing a high degree of negative human activities on habitat and populations). Focusing priority restoration efforts on a large number of subwatersheds within this species' range would be of greatest benefit in increasing habitat quality and projected outcomes for this species.

4.3. Outcomes for forest versus rangeland species

Our projections of environmental and population outcomes under all three management alternatives yielded a surprising contrast for forest versus rangeland species. For most forest-associated species, notable improvements of one or more outcome classes were projected under each alternative, and outcome classes typically improved to the higher classes of A, B, or C. This was not the case for most rangeland species. Outcomes for rangeland species typically did not improve under the alternatives, and often remained in the lower classes of D or E.

We believe this disparity between outcomes of forest versus rangeland species is related to specific landscape model projections for forest communities, as well as the degree to which successional processes and trajectories have been disrupted on rangelands in the Basin (Hemstrom et al., 2001; McIver and Starr, 2001; West, 1999). Much of the forested habitat currently identified as mid-seral, and not as source habitat for many of our species of concern, is projected to transition in 100 years to late-seral forest, which is designated source habitat for several species. A large percentage of these newly developed late-seral forests likely would not be composed of optimal old-growth structures of large, decadent trees, snags, and logs. Thus, our forest modeling projections may be optimistic for any species that actually depend on classic old-growth structural conditions.

Management prescriptions under all alternatives indicate more than 10 times as much land will be treated for rangeland restoration versus forest or woodland restoration. However, rangelands require more time to undergo a positive response to restoration, in part because most rangelands occur in more arid areas than do most woodlands or forests. Many rangelands in the western United States are now believed to follow "state and transition" models of succession, in which certain states cannot be changed due to the dominance of exotic plants that can permanently exclude native vegetation (Hann et al., 1997; West, 1999). In other cases, certain states can only transition to more desirable states through active, intensive restoration efforts applied over major portions of the Basin, which require hundreds of millions of dollars applied over time periods of 100 years or longer (Hann et al., 1997, 2001). For example, West (1999) estimated that up to 50–60% of former sagebrush-steppe in western North America may now have transitioned to states dominated by exotic plants that may be difficult to restore. The slow and varied response of shrub-steppe communities to positive land treatments makes active restoration a challenging and uncertain prospect (Miller and Eddleman, 2000; Tausch et al., 1995).

The threat of exotic plants to recovery of rangeland habitats for terrestrial vertebrates of concern likely will increase in the future; in turn, mitigating such threats presumably will require new, holistic forms of active restoration. We believe such mitigation will be most effective when developed through large-scale management experiments conducted as formal research (as per discussion of Dobkin, 1995). Such large-scale management experiments appear to be a critical component for gaining the knowledge and technology needed to improve rangelands that are degraded currently and are not projected to improve in the future.

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Appendix A

Values of input variables for the population outcome model for all lands and the environmental outcome model for FS–BLM only lands, and expected values of environmental and population outcomes (outcome class in parentheses)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
1	Lewis' woodpecker (migrant)	HIS	100	100	74	Absent	Absent	1.60 (B)	1.60 (B)	100	100	74	1.60 (B)
		CUR	14	33	13	Absent	Absent	4.95 (E)	4.95 (E)	19	38	13	4.95 (E)
		S1_100	29	91	75	Absent	Absent	3.65 (D)	3.65 (D)	37	95	75	3.65 (D)
		S2_100	34	92	72	Absent	Absent	3.65 (D)	3.65 (D)	45	95	72	2.85 (C)
		S3_100	33	92	76	Absent	Absent	3.65 (D)	3.65 (D)	43	96	76	2.85 (C)
1	Pygmy nuthatch	HIS	100	100	95	Absent	Absent	1.05 (A)	1.05 (A)	100	100	95	1.05 (A)
		CUR	20	49	34	Absent	Absent	4.23 (D)	4.23 (D)	30	61	34	4.20 (D)
		S1_100	36	102	95	Absent	Absent	3.00 (C)	3.00 (C)	45	103	95	2.55 (C)
		S2_100	39	102	95	Absent	Absent	3.00 (C)	3.00 (C)	50	103	95	2.55 (C)
		S3_100	38	101	95	Absent	Absent	3.00 (C)	3.00 (C)	49	103	95	2.55 (C)
2	Northern goshawk (summer)	HIS	100	100	98	Absent	Absent	1.05 (A)	1.05 (A)	100	100	98	1.05 (A)
		CUR	40	63	98	Absent	Absent	2.80 (C)	2.80 (C)	51	69	98	2.80 (C)
		S1_100	69	102	98	Absent	Absent	1.72 (B)	1.72 (B)	85	102	98	1.05 (A)
		S2_100	74	102	97	Absent	Absent	1.72 (B)	1.72 (B)	92	102	97	1.05 (A)
		S3_100	73	102	97	Absent	Absent	1.72 (B)	1.72 (B)	91	102	97	1.05 (A)
2	Flammulated owl	HIS	100	100	77	Absent	Absent	1.60 (B)	1.60 (B)	100	100	77	1.60 (B)
		CUR	26	63	43	Absent	Absent	3.95 (D)	3.95 (D)	34	66	43	3.95 (D)
		S1_100	41	103	98	Absent	Absent	2.55 (C)	2.55 (C)	49	102	98	2.55 (C)
		S2_100	44	103	98	Absent	Absent	2.55 (C)	2.55 (C)	53	102	98	2.55 (C)
		S3_100	43	103	98	Absent	Absent	2.55 (C)	2.55 (C)	52	102	98	2.55 (C)
2	Black-backed woodpecker	HIS	100	100	91	Absent	Absent	1.05 (A)	1.05 (A)	100	100	91	1.05 (A)
		CUR	40	66	54	Absent	Absent	3.15 (C)	3.15 (C)	47	68	54	3.15 (C)
		S1_100	63	102	91	Absent	Absent	1.73 (B)	1.73 (B)	73	101	91	1.73 (B)
		S2_100	73	102	91	Absent	Absent	1.73 (B)	1.73 (B)	85	101	91	1.05 (A)
		S3_100	71	102	91	Absent	Absent	1.73 (B)	1.73 (B)	83	101	91	1.05 (A)

Appendix A (*Continued*)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
2	Hoary bat	HIS	100	100	85	Absent	Absent	1.05 (A)	1.05 (A)	100	100	85	1.05 (A)
		CUR	46	101	95	Absent	Absent	2.55 (C)	2.55 (C)	54	91	95	2.55 (C)
		S1_100	59	112	96	Absent	Absent	2.55 (C)	2.55 (C)	71	105	96	1.72 (B)
		S2_100	63	113	96	Absent	Absent	1.72 (B)	1.72 (B)	76	105	96	1.72 (B)
		S3_100	62	112	96	Absent	Absent	1.72 (B)	1.72 (B)	75	105	96	1.72 (B)
2	American marten	HIS	100	100	55	Absent	Absent	1.78 (B)	1.78 (B)	100	100	55	1.78 (B)
		CUR	48	72	23	Absent	Absent	3.95 (D)	3.95 (D)	56	77	23	3.95 (D)
		S1_100	77	105	53	Absent	Absent	2.65 (C)	2.65 (C)	89	105	53	1.78 (B)
		S2_100	79	104	53	Absent	Absent	2.65 (C)	2.65 (C)	90	105	53	1.78 (B)
		S3_100	79	105	53	Absent	Absent	2.65 (C)	2.65 (C)	90	105	53	1.78 (B)
2	Woodland caribou	HIS	100	100	17	Absent	Present	3.45 (C)	4.61 (E)	100	100	17	3.45 (C)
		CUR	50	70	26	Present	Present	3.95 (D)	4.99 (E)	53	72	26	3.95 (D)
		S1_100	106	136	42	Present	Present	1.78 (B)	3.68 (D)	107	137	42	1.78 (B)
		S2_100	106	136	42	Present	Present	1.78 (B)	3.68 (D)	108	136	42	1.78 (B)
		S3_100	106	136	42	Present	Present	1.78 (B)	3.68 (D)	107	136	42	1.78 (B)
3	Blue grouse (summer)	HIS	100	100	99	Absent	Absent	1.05 (A)	1.05 (A)	100	100	99	1.05 (A)
		CUR	78	98	100	Absent	Absent	1.73 (B)	1.73 (B)	77	96	100	1.73 (B)
		S1_100	101	105	100	Absent	Absent	1.05 (A)	1.05 (A)	102	105	100	1.05 (A)
		S2_100	100	105	100	Absent	Absent	1.05 (A)	1.05 (A)	101	105	100	1.05 (A)
		S3_100	100	105	100	Absent	Absent	1.05 (A)	1.05 (A)	100	105	100	1.05 (A)
3	Wolverine	HIS	100	100	82	Absent	Absent	1.05 (A)	1.05 (A)	100	100	82	1.05 (A)
		CUR	54	109	83	Absent	Present	2.55 (C)	3.95 (D)	59	105	83	2.55 (C)
		S1_100	57	109	83	Absent	Present	2.55 (C)	3.95 (D)	65	105	83	1.72 (B)
		S2_100	57	109	83	Absent	Present	2.55 (C)	3.95 (D)	66	105	83	1.72 (B)
		S3_100	58	109	83	Absent	Present	2.55 (C)	3.95 (D)	65	105	83	1.72 (B)
3	Lynx	HIS	100	100	98	Absent	Absent	1.05 (A)	1.05 (A)	100	100	98	1.05 (A)
		CUR	86	101	98	Present	Present	1.05 (A)	2.95 (C)	90	101	98	1.05 (A)
		S1_100	82	101	98	Present	Present	1.05 (A)	2.95 (C)	86	101	98	1.05 (A)

Appendix A (*Continued*)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
		S2_100	83	101	98	Present	Present	1.05 (A)	2.95 (C)	87	101	98	1.05 (A)
		S3_100	83	101	98	Present	Present	1.05 (A)	2.95 (C)	86	101	98	1.05 (A)
4	Lazuli bunting	HIS	100	100	85	Absent	Absent	1.05 (A)	1.05 (A)	100	100	85	1.05 (A)
		CUR	55	65	35	Absent	Absent	3.95 (D)	3.95 (D)	62	74	35	3.30 (C)
		S1_100	90	102	86	Absent	Absent	1.05 (A)	1.05 (A)	92	103	86	1.05 (A)
		S2_100	93	102	80	Absent	Absent	1.05 (A)	1.05 (A)	94	103	80	1.05 (A)
		S3_100	92	102	80	Absent	Absent	1.05 (A)	1.05 (A)	93	103	80	1.05 (A)
5	Gray wolf	HIS	100	100	100	Absent	Absent	1.05 (A)	1.05 (A)	100	100	100	1.05 (A)
		CUR	25	99	100	Absent	Present	3.00 (C)	4.39 (D)	32	100	100	3.00 (C)
		S1_100	24	100	100	Absent	Present	3.00 (C)	4.39 (D)	31	100	100	3.00 (C)
		S2_100	24	100	100	Absent	Present	3.00 (C)	4.39 (D)	31	100	100	3.00 (C)
		S3_100	24	100	100	Absent	Present	3.00 (C)	4.39 (D)	31	100	100	3.00 (C)
5	Grizzly bear	HIS	100	100	100	Absent	Absent	1.05 (A)	1.05 (A)	100	100	100	1.05 (A)
		CUR	25	63	100	Absent	Present	3.75 (D)	4.78 (E)	36	84	100	3.00 (C)
		S1_100	22	57	100	Absent	Present	3.80 (D)	4.80 (E)	32	76	100	3.75 (D)
		S2_100	22	55	100	Absent	Present	3.80 (D)	4.80 (E)	32	75	100	3.75 (D)
		S3_100	22	55	100	Absent	Present	3.80 (D)	4.80 (E)	32	75	100	3.75 (D)
5	Rocky Mountain bighorn sheep (summer)	HIS	100	100	23	Absent	Absent	2.95 (C)	2.95 (C)	100	100	23	2.95 (C)
		CUR	49	96	20	Absent	Present	3.20 (C)	4.50 (E)	57	80	20	3.20 (C)
		S1_100	52	98	23	Absent	Present	3.20 (C)	4.50 (E)	59	81	23	3.20 (C)
		S2_100	53	98	23	Absent	Present	3.20 (C)	4.50 (E)	60	81	23	3.00 (C)
		S3_100	53	98	23	Absent	Present	3.20 (C)	4.50 (E)	60	81	23	3.00 (C)
5	Rocky Mountain bighorn sheep (winter)	HIS	100	100	23	Absent	Absent	2.95 (C)	2.95 (C)	100	100	23	2.95 (C)
		CUR	47	95	19	Absent	Present	4.10 (D)	4.91 (E)	53	77	19	4.13 (D)
		S1_100	52	98	23	Absent	Present	3.20 (C)	4.50 (E)	59	81	23	3.20 (C)
		S2_100	52	97	23	Absent	Present	3.20 (C)	4.50 (E)	60	81	23	3.00 (C)
		S3_100	52	97	23	Absent	Present	3.20 (C)	4.50 (E)	60	81	23	3.00 (C)

Appendix A (*Continued*)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
6	Northern goshawk (winter)	HIS	100	100	97	Absent	Absent	1.05 (A)	1.05 (A)	100	100	97	1.05 (A)
		CUR	72	82	94	Absent	Absent	1.73 (B)	1.73 (B)	71	78	94	2.00 (B)
		S1_100	108	111	100	Absent	Absent	1.05 (A)	1.05 (A)	107	106	100	1.05 (A)
		S2_100	109	111	100	Absent	Absent	1.05 (A)	1.05 (A)	110	106	100	1.05 (A)
		S3_100	109	111	100	Absent	Absent	1.05 (A)	1.05 (A)	110	106	100	1.05 (A)
6	Rufous hummingbird	HIS	100	100	99	Absent	Absent	1.05 (A)	1.05 (A)	100	100	99	1.05 (A)
		CUR	68	90	95	Absent	Absent	1.72 (B)	1.73 (B)	74	95	95	1.73 (B)
		S1_100	95	101	96	Absent	Absent	1.05 (A)	1.05 (A)	98	102	96	1.05 (A)
		S2_100	96	102	95	Absent	Absent	1.05 (A)	1.05 (A)	99	103	95	1.05 (A)
		S3_100	96	102	95	Absent	Absent	1.05 (A)	1.05 (A)	99	103	95	1.05 (A)
7	Long-eared myotis	HIS	100	100	100	Absent	Absent	1.05 (A)	1.05 (A)	100	100	100	1.05 (A)
		CUR	55	101	100	Absent	Absent	2.55 (C)	2.55 (C)	63	101	100	1.73 (B)
		S1_100	51	102	100	Absent	Absent	2.55 (C)	2.55 (C)	58	101	100	2.55 (C)
		S2_100	52	102	100	Absent	Absent	2.55 (C)	2.55 (C)	60	101	100	1.73 (B)
		S3_100	52	102	100	Absent	Absent	2.55 (C)	2.55 (C)	59	101	100	2.55 (C)
8	Western bluebird	HIS	100	100	100	Absent	Absent	1.05 (A)	1.05 (A)	100	100	100	1.05 (A)
		CUR	38	81	99	Absent	Absent	3.00 (C)	3.00 (C)	49	81	99	2.55 (C)
		S1_100	44	98	100	Absent	Absent	2.55 (C)	2.55 (C)	58	100	100	2.55 (C)
		S2_100	46	98	100	Absent	Absent	2.55 (C)	2.55 (C)	62	101	100	1.73 (B)
		S3_100	45	98	100	Absent	Absent	2.55 (C)	2.55 (C)	61	101	100	1.73 (B)
9	Ash-throated flycatcher	HIS	100	100	48	Absent	Absent	1.78 (B)	1.78 (B)	100	100	48	1.78 (B)
		CUR	122	154	42	Absent	Absent	1.78 (B)	1.78 (B)	106	128	42	1.78 (B)
		S1_100	119	153	48	Absent	Absent	1.78 (B)	1.78 (B)	110	138	48	1.78 (B)
		S2_100	117	150	49	Absent	Absent	1.78 (B)	1.78 (B)	106	133	49	1.78 (B)
		S3_100	117	151	52	Absent	Absent	1.78 (B)	1.78 (B)	107	135	52	1.78 (B)
10	Striped whipsnake	HIS	100	100	100	Absent	Absent	1.05 (A)	1.05 (A)	100	100	100	1.05 (A)
		CUR	76	99	100	Absent	Absent	1.73 (B)	1.73 (B)	84	101	100	1.05 (A)
		S1_100	68	99	100	Absent	Absent	1.73 (B)	1.73 (B)	75	100	100	1.73 (B)

Appendix A (*Continued*)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
		S2_100	60	99	99	Absent	Absent	1.73 (B)	1.73 (B)	63	100	99	1.73 (B)
		S3_100	60	99	100	Absent	Absent	1.73 (B)	1.73 (B)	63	100	100	1.73 (B)
10	Short-eared owl	HIS	100	100	89	Absent	Absent	1.05 (A)	1.05 (A)	100	100	89	1.05 (A)
		CUR	27	72	75	Absent	Absent	3.78 (D)	3.78 (D)	41	98	75	2.85 (C)
		S1_100	26	74	84	Absent	Absent	3.75 (D)	3.75 (D)	35	92	84	3.00 (C)
		S2_100	26	75	84	Absent	Absent	3.75 (D)	3.75 (D)	36	94	84	3.00 (C)
		S3_100	26	75	83	Absent	Absent	3.75 (D)	3.75 (D)	36	93	83	3.00 (C)
10	Washington ground squirrel	HIS	100	100	100	Absent	Present	1.05 (A)	2.45 (B)	100	100	100	1.05 (A)
		CUR	14	88	99	Absent	Present	4.00 (D)	4.88 (E)	27	94	99	3.00 (C)
		S1_100	15	91	100	Absent	Present	4.00 (D)	4.88 (E)	24	94	100	3.00 (C)
		S2_100	14	92	100	Absent	Present	4.00 (D)	4.88 (E)	27	94	100	3.00 (C)
		S3_100	14	92	100	Absent	Present	4.00 (D)	4.88 (E)	25	94	100	3.00 (C)
10	Pronghorn	HIS	100	100	96	Absent	Absent	1.05 (A)	1.05 (A)	100	100	96	1.05 (A)
		CUR	53	96	94	Absent	Absent	2.55 (C)	2.55 (C)	58	100	94	2.55 (C)
		S1_100	52	98	97	Absent	Absent	2.55 (C)	2.55 (C)	57	100	97	2.55 (C)
		S2_100	51	98	97	Absent	Absent	2.55 (C)	2.55 (C)	55	99	97	2.55 (C)
		S3_100	51	98	97	Absent	Absent	2.55 (C)	2.55 (C)	55	100	97	2.55 (C)
11	Sage grouse (summer)	HIS	100	100	96	Absent	Absent	1.05 (A)	1.05 (A)	100	100	96	1.05 (A)
		CUR	34	74	67	Absent	Absent	3.78 (D)	3.78 (D)	47	93	67	2.85 (C)
		S1_100	20	77	66	Absent	Absent	3.78 (D)	3.78 (D)	26	93	66	3.65 (D)
		S2_100	22	78	66	Absent	Absent	3.78 (D)	3.78 (D)	30	94	66	3.65 (D)
		S3_100	22	78	66	Absent	Absent	3.78 (D)	3.78 (D)	29	94	66	3.65 (D)
11	Sage grouse (winter)	HIS	100	100	95	Absent	Absent	1.05 (A)	1.05 (A)	100	100	95	1.05 (A)
		CUR	34	75	67	Absent	Absent	3.78 (D)	3.78 (D)	46	93	67	2.85 (C)
		S1_100	27	79	66	Absent	Absent	3.78 (D)	3.78 (D)	36	93	66	3.65 (D)
		S2_100	30	80	66	Absent	Absent	3.65 (D)	3.65 (D)	41	95	66	2.85 (C)
		S3_100	29	79	66	Absent	Absent	3.78 (D)	3.78 (D)	40	94	66	2.85 (C)

Appendix A (*Continued*)

Family	Common name	Alt/time[a]	All Basin lands							FS–BLM lands			
			Input nodes[b]					Environmental outcome	Population outcome	Input nodes			Environmental outcome
			B	D	E	H	K			B	D	E	
11	Brewer's sparrow	HIS	100	100	92	Absent	Absent	1.05 (A)	1.05 (A)	100	100	92	1.05 (A)
		CUR	45	95	90	Absent	Absent	2.55 (C)	2.55 (C)	60	97	90	1.73 (B)
		S1_100	29	100	88	Absent	Absent	3.00 (C)	3.00 (C)	36	101	88	3.00 (C)
		S2_100	30	100	87	Absent	Absent	3.00 (C)	3.00 (C)	40	101	87	2.55 (C)
		S3_100	30	100	87	Absent	Absent	3.00 (C)	3.00 (C)	39	101	87	3.00 (C)
12	Columbian sharp-tailed grouse (summer)	HIS	100	100	58	Absent	Absent	1.78 (B)	1.78 (B)	100	100	58	1.78 (B)
		CUR	19	59	36	Absent	Present	4.85 (E)	4.99 (E)	33	83	36	3.95 (D)
		S1_100	17	63	35	Absent	Present	4.80 (E)	4.98 (E)	26	80	35	3.95 (D)
		S2_100	17	62	34	Absent	Present	4.80 (E)	4.98 (E)	26	79	34	4.20 (D)
		S3_100	17	62	34	Absent	Present	4.80 (E)	4.98 (E)	26	79	34	4.20 (D)
12	Grasshopper sparrow	HIS	100	100	63	Absent	Absent	1.60 (B)	1.60 (B)	100	100	63	1.60 (B)
		CUR	18	56	19	Absent	Absent	4.95 (E)	4.95 (E)	33	92	19	4.25 (D)
		S1_100	14	62	15	Absent	Absent	4.90 (E)	4.90 (E)	19	79	15	4.90 (E)
		S2_100	16	63	12	Absent	Absent	4.90 (E)	4.90 (E)	22	83	12	4.25 (D)
		S3_100	15	63	12	Absent	Absent	4.90 (E)	4.90 (E)	21	83	12	4.25 (D)
N/A	Brown-headed cowbird	HIS	0	0	63	Absent	Absent	4.95 (E)	4.95 (E)	0	0	63	4.95 (E)
		CUR	100	100	63	Absent	Absent	1.60 (B)	1.60 (B)	100	100	63	1.60 (B)
		S1_100	100	99	63	Absent	Absent	1.60 (B)	1.60 (B)	99	98	63	1.60 (B)
		S2_100	100	99	63	Absent	Absent	1.60 (B)	1.60 (B)	99	98	63	1.60 (B)
		S3_100	100	99	63	Absent	Absent	1.60 (B)	1.60 (B)	99	98	63	1.60 (B)

[a] Alternative/time points are historical, current, and alternatives S1, S2, and S3 at 100 years.

[b] See text for description of input nodes B, D, and E in the environmental and population outcome models. Node H is the presence of other influential organisms, such as predators or competitors, that may affect populations, and node K is population size effect (a factor to adjust for demographic effects of small populations).

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