CHAPTER

# Habitat Networks for Terrestrial Wildlife: Concepts and Case Studies

# 19

*Mary M. Rowland and Michael J. Wisdom*

Species of conservation concern, which we define as species with rare or declining populations or habitats, often number in the hundreds or even thousands within a given ecosystem. Moreover, these species typically span a wide spectrum of taxa and are associated with a broad set of ecological characteristics and diverse management challenges. Management designed to fully meet the needs of large numbers of species is by definition impossible: Each species occupies its own niche, and explicitly addressing each of these multidimensional niches would far exceed resources available to managers (Noss and Cooperrider 1994). The management challenge is thus how the many dimensions of multispecies requirements can be reduced to a workable number for practical management application and yet be sufficiently robust to represent the broad, ecological needs of the comprehensive set of species that management must address based on current policies and regulations.

Further complicating this management challenge is the need to address species' requirements in space and time. These requirements vary by activity, season, and life history, and proper arrangement of resources to fulfill these needs within a space compatible with daily and seasonal movements is essential. Moreover, maintenance of desired conditions over time is challenged by pervasive disturbances such as wildfire, exotic species invasions, and human impacts, many of which interact synergistically in ways unpredictable and little understood.

One modeling approach that addresses the spatial and temporal requirements of single or multiple species is the use of habitat networks. We define a habitat network as a spatially explicit portrayal of environmental conditions across large landscapes that can be used to understand the status and trends of species of conservation concern, particularly in relation to how species' needs are met through management of habitat abundance and distribution. Habitat networks are specifically designed to account for and summarize spatial information across landscapes compatible in size and arrangement with the targeted species' activities and movements (Hobbs 2002).

Various alternative definitions have been used for habitat networks, resulting in contrasting applications and interpretations. For example, habitat networks have been defined as "core areas connected by corridors and shielded by buffer zones" (referred to as "ecological networks" by Bani et al. [2002]), "habitat corridors and stepping stones to maintain genetic connectivity between populations" (von Haaren and Reich 2006), "nodes associated with hospitable habitat patches, and links, associated with corridors, for spatial connectivity to support viable metapopulations" (Nikolakaki and Dunnett 2005), and "an interconnected set of habitat elements that together allow for movement of biota and enhance survival probabilities" (Hobbs 2002).

Opdam (2002) defined habitat networks based on the "functional cohesion" among habitat patches in relation to dispersal and other movements, rather than the physical connectedness of patches. Schulte et al. (2006) grouped networks with patchworks and gradients as one class of conservation concepts, "landscape configuration," and described the interrelationships between networks and other theories related to biodiversity conservation. Most definitions of habitat networks, including ours, share two key characteristics: (1) identification of suitable habitat patches and connections among habitat blocks at a scale compatible with species' movements; and (2) evaluation of the entire landscape in relation to meeting species' needs, rather than a limited subset of landscapes such as bioreserves (Haufler 1999).

Habitat networks provide several potential benefits, including (1) conditions for large numbers of species of conservation concern can be addressed efficiently across space and time; (2) a wide variety of habitat characteristics can be holistically integrated; and (3) ecological characterizations provided as part of the network do not dictate a particular form of management, but rather provide the basis for development of a variety of follow-up on management strategies and options.

With these benefits in mind, in this chapter we describe two case examples of habitat networks in conservation planning. Our objectives are to (1) describe the conceptual basis of habitat networks; (2) illustrate practical methods for characterizing habitat networks for species of conservation concern; (3) discuss how network analyses can be interpreted for management; and (4) identify additional knowledge needed for the improved use of networks.

## CONCEPTS OF HABITAT NETWORKS

The conceptual basis for habitat networks stems primarily from conservation theories of island biogeography (MacArthur and Wilson 1967) and metapopulation dynamics (Levins 1969, Hanski and Gilpin 1991), which are the foundations of conservation biology (Noss 1983, Noss and Harris 1986) and landscape ecology (Forman and Godron 1986). As applied to species management, these disciplines share the central tenet of seeking to understand the spatial structure of habitats and its influence on population dynamics. Knowledge of this spatial structure is essential for understanding, and managing for, population persistence. A spatial structure composed of large, relatively unfragmented, and well-connected habitats increases the probability of persistence. Small, fragmented, and isolated habitats decrease that probability.

While such generalizations are logical, understanding the landscape context of habitat—how habitat abundance, patch size, quality, configuration, and connectivity affect persistence of individual species in time and space—is one of the most complicated and challenging aspects of species- and community-level research and management (Hobbs 2002, Bennett 2003). In essence, understanding these spatial characteristics of habitat and their effects on populations is the foundation for habitat networks and their effective application in management (Opdam 2002). Further complicating this challenge is the dynamic nature of habitats, which can change dramatically over time in response to a variety of disturbance regimes.

Although many conceptual and theoretical approaches to habitat networks have been developed (see Hobbs [2002] and Opdam [2002] for review), published examples of practical or "operational" management applications are limited (Hobbs 2002, Schulte et al. 2006). Nonetheless, habitat networks and related conservation concepts (e.g., emphasis areas, patchworks, coarse-filter strategies) have been widely proposed for conservation planning and management (Noss and Cooperrider 1994, Haufler 1999, Hobbs 2002, Opdam 2002, Schulte et al. 2006). Regardless of the specific approach, information considered in designing habitat networks typically includes estimates of abundance, quality, configuration, and connectivity of habitats. (We adhere to the definition of habitat by Hall et al. [1997:3] as "the resources and conditions present in an area that produce occupancy—including survival and reproduction—by a given organism.")

A fundamental premise of habitat networks is that habitat either is naturally fragmented or has become fragmented, and thus some configuration of habitat patches and linkages is necessary to support populations of the species of interest (Vos et al. 2001, Opdam 2002). In a habitat network, contiguous blocks of habitat are defined as habitat patches or core areas and are surrounded by a matrix of nonhabitat or less suitable habitat (e.g., Opdam 2002, Nikolakaki and Dunnett 2005). Linkages or corridors that connect patches also may be explicitly identified. For example, Bani et al. (2002) identified and mapped corridors for avian and carnivore focal species in woodland habitats in a densely populated area in northern Italy by developing an index of "matrix resistance." The lines of lowest resistance represented linkages between core areas of habitat and were located in paths of $30 \times 30$ m cells of the "best available land cover" (Bani et al. 2002).

In our case studies, we further emphasized evaluation of resistance and resiliency of habitats—that is, the degree to which habitats can resist or recover from disturbance. Estimates of population size for local populations and corresponding metapopulations are sometimes considered in network design when spatially explicit demographic, movement, or dispersal data are available (e.g., Bani et al. 2002, Opdam 2002, Gutiérrez 2005, Nikolakaki and Dunnett 2005). However, such data are unavailable for most species of conservation concern (Baguette and Van Dyck 2007), making the network characterization process largely habitat driven and based on more general, but incomplete, knowledge of how species respond to the spatial structure of habitat. Consequently, the challenge is how best to incorporate this incomplete knowledge in designing networks that support persistent populations.

## Steps in Characterizing Habitat Networks

Although each habitat network portrays a unique characterization of environmental conditions, based on objectives of the network and targeted taxa, a basic sequence of steps is applicable in developing most networks (Fig. 19-1; see also Opdam [2002]: Fig. 21.3). We present these steps sequentially; however, some may be undertaken simultaneously or in different order (e.g., species selection, determination of spatial scale). The most critical step in designing a habitat network is the first: developing a well-defined set of objectives or conservation aims (Opdam 2002). Conservation of biodiversity in the planning area is a common network objective (e.g., Opdam 2002, Schulte et al. 2006), but more focused objectives may include protecting particular rare or sensitive species within the planning area (Wiersma and Urban 2005), or identifying blocks of contiguous habitat that are suitable for restoration for species groups (Wisdom et al. 2005*b*).

Depending on the objectives of the network, it may be developed for individual species (Baguette et al. 2000, Nikolakaki and Dunnett 2005), surrogate species, or groups of species with similar environmental requirements or responses to habitat change (Vos et al. 2001; Bani et al. 2002; Wisdom et al. 2002, 2005*b*). If surrogate species or species groups are used to represent the needs of a larger suite of species in a network, a rigorous, peer-reviewed process is needed to establish the surrogates or groups that are assumed to represent the full set of species for which the network is targeted. This process of selecting and using surrogate species or groups of species has been described conceptually and operationally by Wiens et al. (2008). The case example used by Wiens et al. (2008) to illustrate this process drew in part on the data sources and research from the Interior Columbia Basin (Wisdom et al. 2000) that form the basis for our first case example (Wisdom et al. 2002), described later.

Selection of the spatial scale and extent of the network also is important (Fig. 19-1). Ideally, this choice will be dictated by the life history and distribution of the targeted species in the planning area, but in reality the spatial scale of the network is often driven by the resolution and affordability of available spatial data layers. Some trade-offs are necessary, as the selected scale must not only be appropriate in terms of species' ecology, but also match administrative scales used in conservation planning and management.

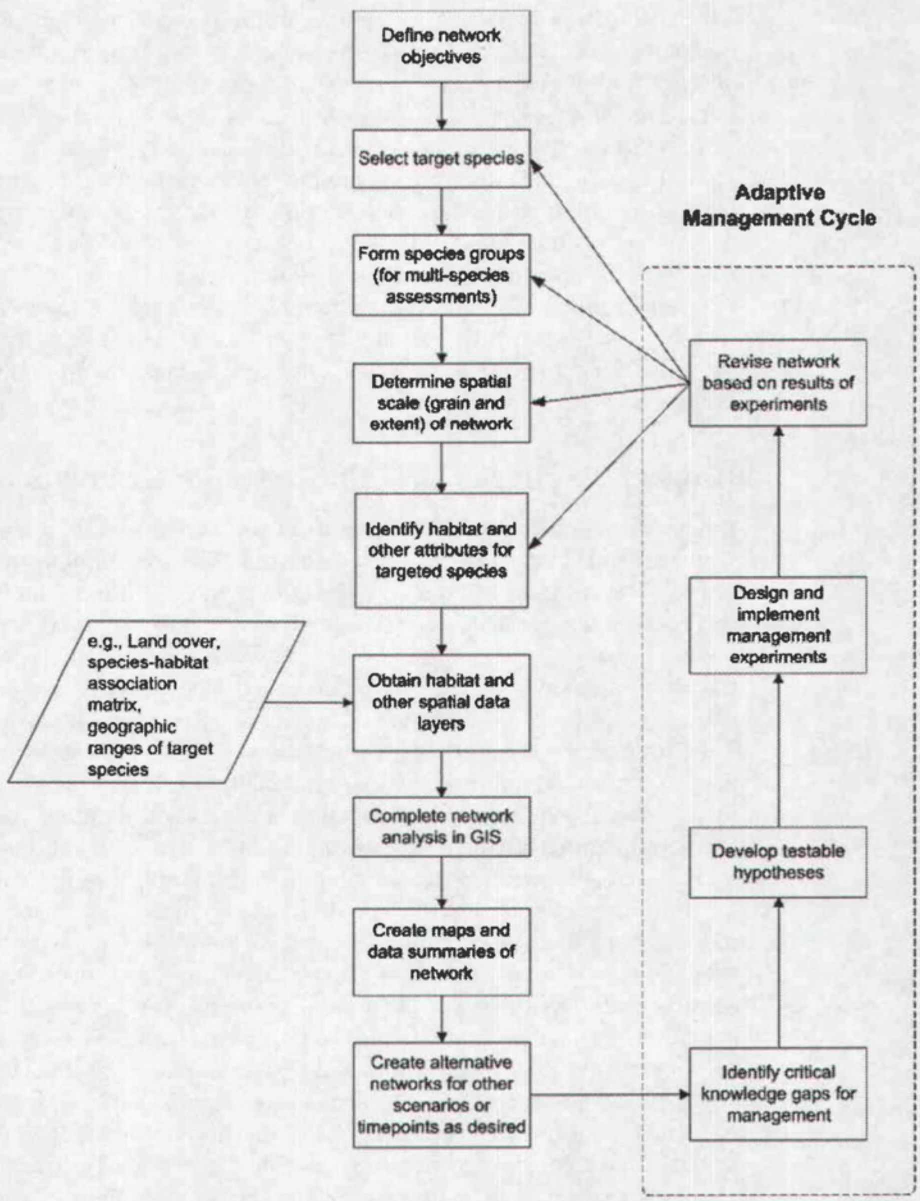



**FIG. 19-1**

Steps in development of a habitat network, including an adaptive management cycle to integrate results of follow-on research in network design.

Classification of habitat for species in the network can be based on a variety of sources, such as existing species-habitat matrices (e.g., Mayer and Laudenslayer 1988), literature review, or expert opinion (Beck and Suring, this volume; Larson et al., this volume). Alternatively, species-habitat associations can be developed explicitly for the network through field studies. For example, León-Cortés et al. (2004) determined habitat associations for a unique butterfly species, *Baronia brevicornis*, in southern Mexico by walking >1,300 transects while developing a habitat network for conservation of this species. Regardless of origin, the specificity of habitat as defined for the network will strongly influence measures of habitat abundance and connectivity (Hobbs 2002). Information beyond habitat may be included in the network, such as key ecological processes that affect target species, effects of human disturbance, or population density.

## Habitat Networks as Wildlife Habitat Models

Habitat networks have been variously defined, but all definitions support the concept of habitat networks as models: abstractions or simplifications of the real world (Nichols 2001). We can never completely identify or accurately measure the comprehensive suite of environmental conditions that constitute habitat, or habitat linkages, for a species. We can, however, with varying levels of certainty, measure and map habitat components that are consistently associated with population status or trends for targeted species of concern, such as amount of interior old-growth forest for northern spotted owls (*Strix occidentalis caurina;* Franklin et al. 2000; Hicks et al., this volume). For many species, especially birds and mammals, these components typically include vegetation structure and composition and the quantity, quality, and configuration of these in the landscape, which can be spatially depicted in a geographic information system (GIS).

A prerequisite for assessing the utility of any model is a clear statement of the model's objectives (Millspaugh et al., this volume). In the creation of habitat networks, very different model structures and inputs may be realized, depending on network objectives. For example, consider two contrasting objectives: conservation of all native biota within a defined landscape versus habitat restoration for a particular species group. In the first example, habitat patches for the network would be selected from a broad cross-section of ecosystem conditions to encompass the greatest biodiversity. Model inputs might include measures of species richness, land ownership, and land cover. By contrast, in the second example existing and potential habitat for species in the group would be mapped, and areas with high restoration potential would be emphasized. Model inputs in this case might include population and habitat distribution data for species in the group, estimated restoration potential, and risk of habitat loss. Careful consideration of the resulting habitat network and its utility in meeting its prescribed objectives is imperative: "What are my conservation objectives? Will the habitat network as designed help meet them?"

Habitat networks might not be a pragmatic or effective tool in meeting all conservation objectives, such as habitat restoration for very rare species with limited known distributions, in which case all habitat patches would be identified and targeted for maintenance or restoration, regardless of their spatial relationship. Alternatively, species for which habitat is poorly defined, especially species with no known strong alliance with vegetation composition or structure, might not be suitable candidates for development of a habitat network, especially at landscape levels. In general, however, species that occupy large landscapes and for which spatial population structure and distribution of habitats are important will likely benefit from a network approach.

## Spatial and Temporal Basis of Habitat Networks

Habitat networks exemplify spatial relationships in wildlife ecology; habitat patches are not only defined and located, but also mapped in relation to each other. Mapping habitat networks in a GIS thus allows for "spatial depictions of theoretical constructs," such as core habitat and linkages (O'Neil et al. 2005:418). Habitat networks are most appropriately applied across large landscapes, such as multiple watersheds or subbasins, or even ecoregions, for two reasons. First, these large spatial extents typically encompass the seasonal or year-round ranges of individuals or populations of many wide-ranging species. Second, the data layers commonly available to construct networks often lack the resolution to accurately depict fine-scale habitat features (Opdam 2002). Thus, habitat networks are typically characterized by coarse-scale features (e.g., canopy cover of dominant vegetation or topographically derived variables), rather than fine-scale features (e.g., site-specific forage resources or seeps, springs, and caves).

Another consideration in development of a habitat network in GIS is data type (Roloff et al., this volume). Ideally, the network should be developed from primary base data layers (e.g., tree density by size class), rather than derived or interpreted attributes, such as existing vegetation classes (O'Neil et al. 2005). Thus, if habitat is redefined for some targeted species through the development of new habitat relationship models, the base layers may still be used to map habitat in the new network without re-creating the entire system.

Habitat networks are typically developed to represent current environmental conditions (e.g., Baguette et al. 2000, Bani et al. 2002). However, networks can also be used to project future conditions or conditions under alternative management scenarios (Verboom et al. 2001, Opdam 2002). For example, a habitat network was designed for red deer (*Cervus elaphus*) in northwestern Europe that identified areas not currently occupied, but that could support viable populations in the future (Bruinderink et al. 2003). Effects of climate change on future spatial patterns of habitat and metapopulations will require dynamic network models that portray a range of potential outcomes (Opdam and Wascher 2004). Alternatively, a habitat network can reflect changes from historical to current conditions (e.g., Wisdom et al. [2002] and "Case Studies" below). Ultimately, the objectives of the network will dictate its spatial and temporal scale.

## CASE STUDIES

We present two examples of habitat networks. Both were developed for use in broad-scale land management and conservation planning in the western United States, and evaluated habitat conditions for groups of terrestrial vertebrates of conservation concern across multiple land ownerships and state boundaries. All vertebrates selected for analysis were wide-ranging and not reliant on fine-scale habitat features (e.g., riparian corridors), and thus were suitable for assessment across large landscapes. In the first example, habitat networks in the Interior Columbia Basin were characterized by measures of habitat abundance coupled with measures of habitat resiliency and quality. In the second, composite habitat conditions in the Great Basin were based on estimates of habitat abundance and risk of habitat loss.

Many other landscape and ecological characteristics beyond measures of habitat abundance and quality can be incorporated in habitat networks, including dispersal rates, predicted population persistence, and connectivity (Bani et al. 2002, Opdam 2002). Studies in which dispersal and movement behavior of multiple species have been explicitly considered in the use of habitat networks include work with the marshland bird networks in The Netherlands (Verboom et al. 2001), disturbance-sensitive mammals in the Yukon, Canada (Wiersma and Urban 2005), woodland birds and mammalian carnivores in Italy (Bani et al. 2002), and butterfly species networks in southern Belgium (Baguette et al. 2000).

Our case examples address problems and conditions commonly faced by managers charged with maintenance and recovery of habitats and populations of large numbers of species of conservation concern. First, landscapes in our examples are vast, encompassing millions of hectares; consequently, the available spatial data were coarse in resolution and limited in numbers and types of habitat variables represented. Second, the number of species to be addressed (40 and 91 for the two examples) was too great to allow development of networks for individual species, thus necessitating the use of species groups in network designs. And third, knowledge of the species' habitat requirements was highly variable and incomplete, with little spatially explicit demographic or movement data available for many species, thus requiring use of more general knowledge of species' associations with dominant existing vegetation cover types and the abundance and arrangement of these cover types in space and time. While these issues constrained the potential approaches to characterize habitat networks in the two case examples, the networks designed for each case example supported the management goal to characterize broad-scale habitat conditions for a comprehensive set of targeted species.

Use of surrogate species or groups of species, in particular, has been criticized as not reflecting the needs of the full suite of species that the surrogate or group is intended to represent. This criticism was addressed in detail by Wiens et al. (2008), who described conditions for which surrogate species and species grouping methods were not only helpful but necessary for effective management. These conditions included (1) a large number of species to be addressed (e.g., >50 species), such that individual species management is infeasible; (2) a management area intermediate in size, between continental areas (too large) and local assemblages of patches (too small); and (3) sufficient knowledge of taxa requirements and associated spatial data, allowing habitat conditions to be mapped and assessed and application of rigorous, quantitative methods to select surrogates or groups from the full set of species.

## Interior Columbia Basin

*Background.*—The Interior Columbia Basin Ecosystem Management Project (ICBEMP) was a cooperative endeavor between the U.S. Forest Service (USFS) and Bureau of Land Management (BLM). The project's aim was to develop an ecosystem-based strategy for USFS- and BLM-managed lands across the vast expanse (58 million ha) of the Interior Columbia Basin (hereafter referred to as "Columbia Basin;" Fig. 19-2) (U.S. Forest Service 1996; see also Gravenmier et al. [1997] and Hann et al. [1997] for further description of the Columbia Basin and ICBEMP). The science assessment area of the ICBEMP extended from northwest Washington to Wyoming, with public lands composing 53%. This monumental multiyear and multiscale effort was undertaken to develop an ecosystem-wide management plan to supersede >50 existing federal land management plans in place at the onset of the project in 1994 (U.S. Forest Service 1996).

As part of science assessments for the ICBEMP, a coarse-scale evaluation of habitat conditions for 91 species of upland terrestrial vertebrates of concern was conducted (Wisdom et al. 2000). Habitats for individual species, as well as for species groups and "families" of groups, were analyzed at multiple spatial scales using a hierarchical classification system to assign species to groups and groups to families (Wisdom et al. 2000). Habitat trends were assessed by comparing current (mid-1990s) with historical (circa 1850–1890) conditions. The habitat network analysis described here was conducted as part of the ICBEMP.

Of the 91 species for which conditions were assessed, 44 species, composing five families and 19 groups, were selected for the habitat network analysis. The species in these five families were characterized by declining habitat conditions, range contractions, and relatively narrow habitat requirements; the families included species associated with old forests, forest stand initiation, sagebrush (*Artemisia* spp.), and grasslands. The primary goal in creating the habitat networks was to characterize broad-scale conditions that reflected composite differences among species in the quantity, quality, and connectivity of habitat (Wisdom et al. 2002:3).

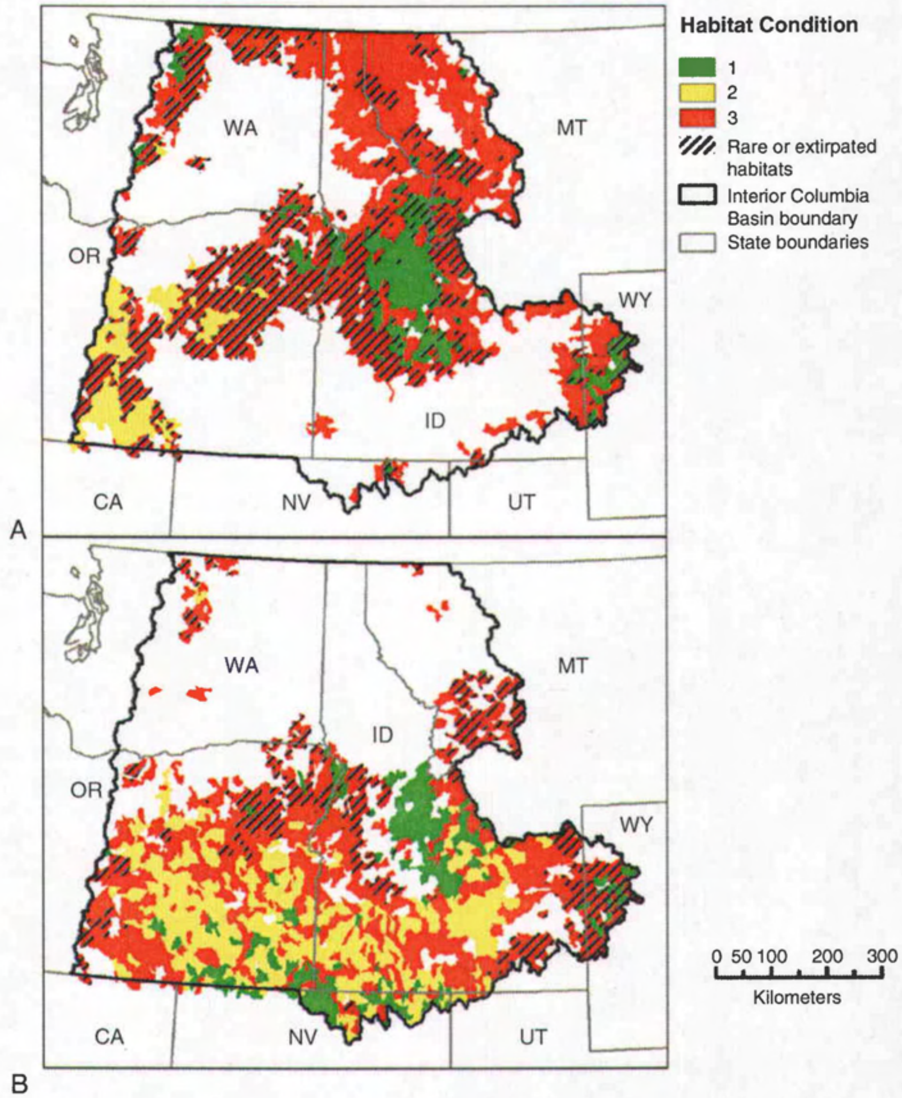



**FIG. 19-2**

Habitat network for Family 1 (old forest, low elevation; A) and Family 11 (sagebrush; B) in the Interior Columbia Basin, USA. See text for explanation of habitat condition classes and rare or extirpated habitats. Blank areas are watersheds that contain no public lands or are outside the range of the family. Adapted from Wisdom et al. (2002).

Assumptions of the habitat network analysis included (1) local (i.e., small-scale) assessments would be conducted to complement the broad-scale characterization provided by the networks; (2) suitable habitats were correctly identified for the species of concern; and (3) the broad-scale approach provided by the habitat networks would assist in conservation planning over the entire Columbia Basin, not only for the 44 species evaluated, but also for other species of concern whose habitats overlapped those of the selected species.

*Methods.*—Coarse-scale (1-km$^2$ pixels) measures of habitat conditions for the 44 selected terrestrial vertebrates were evaluated by using two variables: (1) habitat abundance and (2) disturbance departure and fragmentation, which reflects habitat quality and resiliency. Habitat was mapped for each species with a comprehensive species-habitat association matrix developed explicitly for the ICBEMP (Wisdom et al. 2000). Digital maps of historical and existing vegetation cover types and structural stages in the Columbia Basin were derived from a vegetation succession model developed for the ICBEMP (Keane et al. 1996, Hann et al. 1997). Species experts then used the >150 cover type-structural stage combinations, such as old multistory western larch (*Larix occidentalis*), to assign habitat for each species in the matrix. Habitat was then mapped in a GIS for each species within its geographic range in the Columbia Basin. See Wisdom et al. (2000) for additional methods of identifying, quantifying, and mapping habitat for the species.

To measure habitat abundance, habitat at the watershed level (5th hydrologic unit code; Gravenmier et al. 1997) was mapped and summarized for each of the 19 groups to which the 44 species were assigned. Next, mean abundance (in hectares) of habitat among all groups within a family was calculated for each watershed ($n$ = 2,562 watersheds) in the Columbia Basin. Watersheds for each family were then ranked from highest to lowest, based on mean habitat abundance, and assigned to one of three classes: (1) Class A, which included all watersheds in the top two quartiles; (2) Class B, watersheds in the next lowest (third) quartile; and (3) Class C, watersheds in the lowest quartile of habitat abundance.

The second variable, the disturbance departure and fragmentation index (hereafter referred to as disturbance departure), reflects composite effects of changes from the natural or native system at multiple scales (Hann et al. 2003). The variable represents several broad-scale processes related to habitat quality and resiliency, such as changes in vegetation patch size, composition, and arrangement; frequency and intensity of fire; composition of native versus nonnative vegetation; and human disturbance. The index was derived from three primary, coarse-scale input variables: landscape management pattern, landscape vegetation pattern, and potential vegetation group pattern (Hann et al. 2003). These three variables were selected as those most useful for "accurately representing the major patterns and effects of human activities and management on the quality and resiliency of wildland landscapes in the Basin" (Hann et al. 2003:5). The disturbance departure variable was derived as four classes—low, moderate, high, and very high—with the last representing the greatest deviation from historical conditions. Each watershed in the Columbia Basin was assigned to one of these four classes.

The three classes of habitat abundance were then combined with the four classes of disturbance departure to create three habitat condition classes for each family, at the watershed level, during the current time period:

1. *Condition 1:* Watersheds with low disturbance departure and any class of habitat abundance. Such watersheds were considered very resilient and to have changed little in habitat abundance or quality since historical times.
2. *Condition 2:* Watersheds with moderate disturbance departure and habitat abundance in Class A. Conditions in these sites reflect moderate resiliency and some degradation in quality, but relatively abundant habitat.
3. *Condition 3:* All other watersheds not classified as Condition 1 or 2. Watersheds in this class typically contained degraded and uncommon, rare (present but <1% of the watershed), or extirpated habitats.

Each watershed was assigned to a condition class for a family if the current geographic range of any species in the family overlapped the watershed and the watershed contained habitat for that species, either historically or currently. Resulting habitat condition classes were mapped across the Columbia Basin for each of the five families for the current time period, with the exclusion of 461 (18%) watersheds that contained no public lands.

Last, watersheds were highlighted in which habitat for a family was present historically but either had been extirpated or was now rare. Although no formal connectivity analysis was conducted, spatial gaps in connectivity that could be addressed through habitat restoration and conservation planning were identified by this analysis. Spatial gaps in connectivity were characterized as watersheds in Condition 3 with rare or extirpated habitats that were adjacent to watersheds in Condition 1 or 2. Such Condition 3 watersheds represented areas where the greatest declines in habitat abundance and quality had occurred, and where increasing connectivity through restoration would be most beneficial. Those situations were noted in terms of the geographic areas in which these types of habitat "gaps" were present (Wisdom et al. 2002).

*Results.*—Here we focus on results for two contrasting families, Family 1 (old forest, low elevation) and Family 11 (sagebrush; Table 19-1). Habitat for Family 1 species was broadly distributed across forested areas of the Columbia Basin (Fig. 19-2A). Likewise, the sagebrush habitats of Family 11 were found throughout the Columbia Basin, primarily in lower-elevation rangelands but especially in eastern Oregon and central and southern Idaho (Fig. 19-2B).

Condition 3 was dominant among watersheds for both families, especially Family 1, indicating substantial declines in amount, quality, and resiliency of habitats for species in these families (Table 19-2, Fig. 19-2). Moreover, habitat

**Table 19-1** Vertebrate Species of Conservation Focus from Families 1 and 11, Selected for Characterization of Habitat Conditions in the Interior Columbia Basin (Adapted from Wisdom et al. [2000, 2002])

| Family | Group | Common Name | Scientific Name |
|---|---|---|---|
| 1 (old forest, low elevation)[a] | 1 | White-headed woodpecker | *Picoides albolarvatus* |
| | 1 | White-breasted nuthatch | *Sitta carolinensis* |
| | 1 | Pygmy nuthatch | *Sitta pygmaea* |
| | 2 | Lewis' woodpecker | *Melanerpes lewis* |
| | 3 | Western gray squirrel | *Sciurus griseus* |
| 11 (sagebrush)[b] | 33 | Greater sage-grouse | *Centrocercus urophasianus* |
| | 33 | Sage thrasher | *Oreoscoptes montanus* |
| | 33 | Brewer's sparrow | *Spizella breweri* |
| | 33 | Sage sparrow | *Amphispiza belli* |
| | 33 | Lark bunting | *Calamospiza melanocorys* |
| | 33 | Pygmy rabbit | *Brachylagus idahoensis* |
| | 33 | Sagebrush vole | *Lemmiscus curtatus* |
| | 34 | Black-throated sparrow | *Amphispiza bilineata* |
| | 34 | Kit fox | *Vulpes macrotis* |
| | 35 | Loggerhead shrike | *Lanius ludovicianus* |

[a]*Habitats consist primarily of lower montane forests in late-seral condition.*
[b]*Habitats consist primarily of sagebrush communities.*

has been extirpated in many of the watersheds in this condition class; for example, more than one third of the watersheds for Family 1 in Condition 3 no longer support habitat for species in this family (Table 19-2). Watersheds with rare or extirpated habitat were widely distributed across the current range of species in both families (Table 19-2, Fig. 19-2).

Families 1 and 11 also had the lowest percentage of watersheds in Condition 1 among all five families, evidence of the paucity of habitats resembling historical conditions for these species. A large majority of watersheds in Condition 1 (64–81%) for both families was found in protected areas such as national parks, wilderness, or roadless areas (Wisdom et al. 2002). Condition 2, representing moderate disturbance departure but relatively abundant habitat, was rare (6%) for Family 1. By contrast, Family 11 had the greatest percentage (25%) of watersheds in Condition 2 among all families (Table 19-2).

**Table 19-2** Watersheds by Habitat Condition Class and those Containing Extirpated or Rare Habitats for Two Families of Vertebrate Species of Conservation Focus in the Interior Columbia Basin (See Text and Wisdom et al. [2002] for Details)

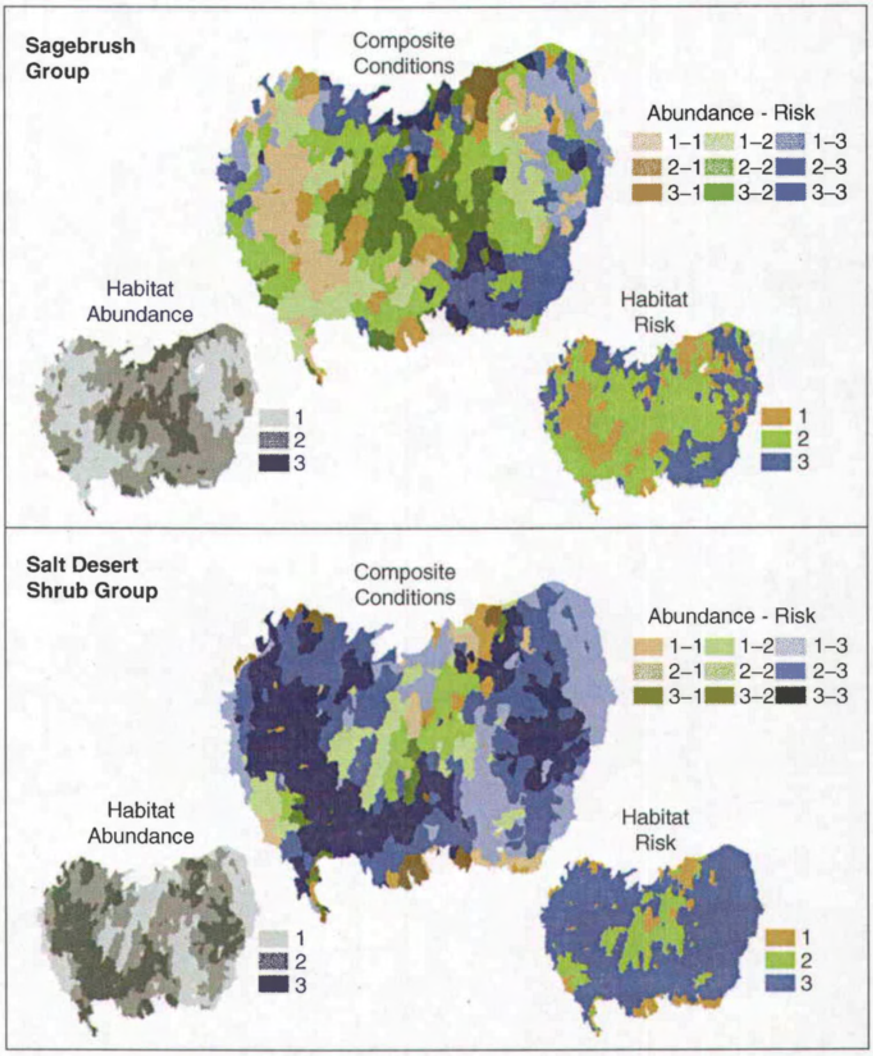
| | | | Percentage of Watersheds | | |
|---|---|---|---|---|---|
| **Family** | ***n*** | **Habitat Condition Class** | **By Habitat Condition** | **With Extirpated Habitats** | **With Rare Habitats** |
| 1 | 1,248 | 1 | 14 | 0 | 4 |
| | | 2 | 6 | 0 | 0 |
| | | 3 | 80 | 30 | 11 |
| | | All | 100 | 30 | 15 |
| 11 | 1,229 | 1 | 15 | 0 | <1 |
| | | 2 | 25 | 0 | 0 |
| | | 3 | 59 | 15 | 5 |
| | | All | 100[a] | 15 | 5 |

[a]*Discrepancies between sums in columns are due to rounding.*

## Great Basin

*Background.*—Habitats for species associated with the sagebrush ecosystem have undergone dramatic declines in extent and quality since European settlement (Knick et al. 2003, Wisdom et al. 2005*a*, Chambers et al. 2007). Causes of these changes are diverse, and include intensive livestock grazing, energy extraction, invasion of exotic species such as cheatgrass (*Bromus tectorum*), encroachment of pinyon-juniper woodlands (*Pinus* spp. - *Juniperus* spp.), and altered fire regimes (Knick et al. 2003, Wisdom et al. 2005*a*). These alterations have prompted resource managers to develop and apply innovative approaches to conserve and restore habitats for sagebrush-associated species (e.g., Bureau of Land Management 1999).

In response, we conducted a regional assessment of habitat threats for vertebrate species of concern in the Great Basin Ecoregion, which encompasses most of Nevada and portions of eastern California and western Utah (Fig. 19-3; Nachlinger et al. 2001). This region not only harbors some of the most extensive remaining expanses of sagebrush in the United States, but also has experienced unprecedented losses of sagebrush from catastrophic wildfires (Nachlinger et al. 2001, Rowland and Wisdom 2005, Chambers et al. 2007). The BLM, which manages the majority (52%) of sagebrush nationwide, solicited and funded the Great Basin assessment to help meet its goal to complete broad-scale assessments of




A

B

**FIG. 19-3**

Habitat abundance, habitat risk, and composite habitat conditions (all combinations of habitat abundance and risk) for the sagebrush (A) and salt desert shrub (B) groups of species in watersheds of the Great Basin Ecoregion, USA. See text for explanations of habitat abundance and risk classes. For composite conditions, the first number represents the abundance class; and the second number, the risk class (e.g., 1-3 is low habitat abundance and moderate-high risk). Mean size of the 367 watersheds that occur entirely within the ecoregion was 66,000 ha; $n$ = 521 for all watersheds intersecting the ecoregion. Adapted from Wisdom et al. (2005*b*).

habitat conditions in all ecoregions of the sagebrush ecosystem (Wisdom et al. 2005*a*). To initiate this project, a series of protocols was developed for regional assessment of habitats in sagebrush ecosystems (Wisdom et al. 2005*a*). These protocols include selection of species of conservation concern, assignment of species to groups, and estimation of habitats at risk for individual species and species groups.

Primary goals of the Great Basin assessment were to (1) evaluate habitat conditions and threats for selected species of concern; (2) demonstrate application of the newly developed protocols in the Great Basin; and (3) describe the application of results for land management and conservation planning. Secondary goals related to the use of species groups were to (1) reveal regional patterns of habitat conditions and (2) characterize habitat conditions at the watershed level for land management planning.

*Methods*.—Forty vertebrates of concern, including 13 mammals, 17 birds, and 10 herptiles, were selected for analysis (Table 19-3). Criteria for selection

**Table 19-3** Vertebrate Species of Conservation Concern Selected for Assessment in the Great Basin Ecoregion (From Wisdom et al. 2005*b*)

| Group | Common name | Scientific name |
|---|---|---|
| Sagebrush | Greater sage-grouse | *Centrocercus urophasianus* |
| | Sage thrasher | *Oreoscoptes montanus* |
| | Sage sparrow | *Amphispiza belli* |
| | Vesper sparrow | *Pooecetes gramineus* |
| | Brewer's sparrow | *Spizella breweri* |
| | Wyoming ground squirrel | *Spermophilus elegans nevadensis* |
| | Pygmy rabbit | *Brachylagus idahoensis* |
| Salt desert shrub | Great Basin collared lizard | *Crotaphytus bicinctores* |
| | Long-nosed leopard lizard | *Gambelia wislizenii* |
| | Desert horned lizard | *Phrynosoma platyrhinos* |
| | Desert spiny lizard | *Sceloporus magister* |
| | Long-nosed snake | *Rhinocheilus lecontei* |
| | Groundsnake | *Sonora semiannulata* |
| | Merriam's kangaroo rat | *Dipodomys merriami* |
| | Chisel-toothed kangaroo rat | *Dipodomys microps* |

*continues*

**Table 19-3** Vertebrate Species of Conservation Concern Selected for Assessment in the Great Basin Ecoregion (From Wisdom et al. 2005*b*) *cont...*

| Group | Common name | Scientific name |
|---|---|---|
| Sagebrush-woodland | Gray flycatcher | *Empidonax wrightii* |
| | Green-tailed towhee | *Pipilo chlorurus* |
| | Merriam's shrew | *Sorex merriami* |
| | Sagebrush vole | *Lemmiscus curtatus* |
| | White-tailed jackrabbit | *Lepus townsendii* |
| Shrubland | Common sagebrush lizard | *Sceloporus graciosus* |
| | Northern harrier | *Circus cyaneus* |
| | Prairie falcon | *Falco mexicanus* |
| | Short-eared owl | *Asio flammeus* |
| | Western burrowing owl | *Athene cunicularia hypugaea* |
| | Loggerhead shrike | *Lanius ludovicianus* |
| | Black-throated sparrow | *Amphispiza bilineata* |
| | Kit fox | *Vulpes macrotis* |
| | Pronghorn | *Antilocapra americana* |
| | Ord's kangaroo rat | *Dipodomys ordii* |
| | Dark kangaroo mouse | *Microdipodops megacephalus* |
| | Little pocket mouse | *Perognathus longimembris* |
| | Northern grasshopper mouse | *Onychomys leucogaster* |
| Generalist | Great Basin spadefoot | *Spea intermontana* |
| | Nightsnake | *Hypsiglena torquata* |
| | Striped whipsnake | *Masticophis taeniatus* |
| | Ferruginous hawk | *Buteo regalis* |
| | Swainson's hawk | *Buteo swainsoni* |
| | Lark sparrow | *Chondestes grammacus* |
| | Brewer's blackbird | *Euphagus cyanocephalus* |

included association with sagebrush habitats and with habitat features that can be accurately mapped with coarse-scale data, a geographic range encompassing >5% of the study area (or about 1.5 million ha), and risk status (determined from state-level ranks obtained from NatureServe [2005]) (Wisdom et al. 2005*a*). For example, rock wrens (*Salpinctes obsoletus*) and rock squirrels (*Spermophilus variegatus*) were dropped from the list due to their strong affinity for rock outcrops, which could not be feasibly mapped at the spatial extent of our study area. The 40 species selected represented a diverse group of widely distributed sagebrush-associated species (Table 19-3).

We quantified habitat for each species within its geographic range in the ecoregion using a species-habitat association matrix as follows. Existing vegetation in the study area was mapped with a land cover classification of 90-m resolution developed for regional assessment of sagebrush habitats in the western United States (Comer et al. 2002), but that incorporated all existing vegetation types. This coverage included 47 land cover types (e.g., mountain big sagebrush [*Artemisia vaseyana*]) in the Great Basin. We developed a habitat association matrix for the 40 species of concern with this land cover layer, based on existing species-habitat databases (e.g., Maser et al. 1984) and consultation with species experts. Ideally, habitat would have been identified for the network by conducting field studies to document occurrence or abundance of the species of interest in various cover types within the Great Basin, but the immense size of the study area and number of species in the assessment precluded such data collection.

Each of the 40 species was then assigned to one of five groups—sagebrush, shrubland, salt desert shrub, sagebrush-woodland, and generalist—based on similarities in habitat associations and habitat abundance among species in each group. Current habitat conditions for each group were evaluated by watersheds, due to the increasing prevalence and preference of this spatial extent for research and management in sagebrush ecosystems of the western United States (Bureau of Land Management 1999, Wisdom et al. 2005*b*).

For each watershed and species group, habitat abundance and risk of habitat loss were estimated and mapped, and then combined to estimate composite habitat conditions. To quantify habitat abundance for species groups, the amount and percentage of habitat for each species were first calculated in each watershed within the species' range in the study area. Next, the mean percent habitat across all species within a group was calculated at the watershed level. Last, habitat abundance was classified, by group, in each watershed as follows: (1) low: mean habitat <25%; (2) moderate: mean habitat 25–50%; and (3) high: mean habitat >50%.

To estimate risk of habitat loss, a rule-based model of risk of displacement of native vegetation by cheatgrass was developed and applied (Suring et al. 2005). Model output was classified as none, low, moderate, or high risk for each 90-m pixel in the study area. At the watershed level, the percentage of each species' habitat within the four risk categories was calculated. The mean percent habitat, by risk category, was then calculated among all species in each group. Last, watersheds were classified as follows: (1) none-low: habitat in the none and low-risk categories combined >50%; (2) low-moderate: habitat in the low- and moderate-risk categories combined >50%; and (3) moderate-high: habitat in the moderate- and high-risk categories combined >50%. Finally, the three habitat abundance classes were combined with the three risk classes, yielding nine possible combinations for assignment of habitat condition at the watershed level.

*Results.*—Here we present a subset of the results of the Great Basin assessment, concentrating on the contrasting patterns for the sagebrush and salt desert shrub species groups. Across the Great Basin, habitat abundance for the sagebrush group was dominated by the moderate class, or watersheds with mean habitat from 25–50% of the watershed area (Table 19-4, Fig. 19-3A). This group also had the lowest percentage (22%) of watersheds in the high abundance class among all groups, indicating that relatively few watersheds in the Great Basin are currently dominated by sagebrush habitats. In contrast to this pattern, results for the salt desert shrub group indicated an even distribution of watersheds among the three classes of habitat abundance (Table 19-4, Fig. 19-3B). Watersheds with the most habitat for species in the sagebrush group were in the mountains of the ecoregion's center and along its northern edge; habitat for salt desert shrub species was most abundant in the western and eastern portions of the ecoregion, with less habitat in the central area (Fig. 19-3).

**Table 19-4** Percentage of Watersheds in the Great Basin by All Combinations of Habitat Abundance and Risk for Two Sample Species Groups (Adapted from Wisdom et al. 2005*b*)

| | | | Risk of Habitat Displacement by Cheatgrass | | | |
|---|---|---|---|---|---|---|
| **Species Group** | ***n*** | **Habitat Abundance** | **None-Low** | **Low-Moderate** | **Moderate-High** | **All Risk Classes Combined** |
| Sagebrush | 168 | Low | 14 | 10 | 9 | 32[a] |
| | 236 | Moderate | 7 | 21 | 18 | 46 |
| | 115 | High | 2 | 14 | 7 | 22 |
| | 519 | Total | 24 | 44 | 32 | 100 |
| Salt desert shrub | 180 | Low | 6 | 8 | 21 | 35 |
| | 156 | Moderate | 4 | 4 | 23 | 31 |
| | 171 | High | 5 | 3 | 26 | 34 |
| | 507 | Total | 14 | 15 | 71 | 100 |

[a]*Discrepancies between sums and numbers in rows and columns are due to rounding.*

Patterns of habitat risk contrasted sharply between the two groups, both quantitatively and spatially. Watersheds for the sagebrush group were somewhat equally divided among the three risk classes, although the none-low risk class was least common (24%). However, moderate-high risk was clearly the dominant class for species in the salt desert shrub group (Table 19-4, Fig. 19-3B). For the sagebrush group, lower-risk habitat was distributed throughout the ecoregion but especially scarce in the central portion (Fig. 19-3A). Higher-risk habitats were found along the eastern and northern perimeter of the study area. Spatial patterns of habitat risk for the salt desert shrub group were markedly different from those for the sagebrush group, with high-risk habitat blanketing most of the ecoregion, with the exception of the central core (Fig. 19-3B).

Examination of composite conditions revealed that watersheds in the "best condition," i.e., those with abundant habitat at low risk (abundance-risk class 3-1), were very rare for both groups (Table 19-4, Fig. 19-3). The most common composite condition was that of moderate habitat abundance with low-moderate risk (class 2-2; 21%) for the sagebrush species group, and high habitat abundance with moderate-high risk (class 3-3; 26%) for the salt desert shrub group (Table 19-4, Fig. 19-3).

*Discussion.*—The two case studies of habitat networks share several traits, including (1) use of species groups, (2) incorporation of past disturbance or future risk, and (3) "wall-to-wall" characterization of regional habitat conditions across all land ownerships. In both the Columbia Basin and Great Basin, separate networks were developed for groups of species that contrasted in their habitat associations and past levels of habitat loss (Columbia Basin) or predicted risk of habitat loss (Great Basin). Other authors also have described network approaches for species groups; for example, Vos et al. (2001) grouped species by "ecological profile" using individual area requirements and dispersal distance to reflect metapopulation response to landscape change.

Use of disturbance departure in the Columbia Basin and risk of habitat loss from displacement by cheatgrass in the Great Basin provided further discrimination between watersheds with similar amounts of habitat but often dramatically different risk. Such an approach goes beyond simple identification of habitat patches within a network, and parallels that of McIntyre and Hobbs (1999), who used a continuum of habitat loss factors to characterize habitat in the matrix. Similarly, Frank (2004) described "strong" habitat patches, based on distance to neighboring patches that were able to withstand negative effects of environmental stochasticity.

The two case examples demonstrate spatial characterization of regional-level habitat conditions across multiple landscapes and ownerships, providing a springboard for more small-scale evaluations to determine what specific locales within watersheds warrant management action and what actions are feasible. This contrasts with habitat networks that identify individual habitat patches or core areas and corridors between patches (e.g., Bani et al. 2002, Nikolakaki and Dunnett 2005). Portions of our networks, however, can be interpreted more traditionally. For example, condition 3 watersheds in the Columbia Basin are most likely dominated by matrix habitats, with few functioning "core" habitat patches remaining. Well-informed management of the "semi-natural matrix" that constitutes most of the land area in the United States (Noss and Cooperrider 1994) may be the most prudent approach to biodiversity conservation.

## POLICY AND MANAGEMENT IMPLICATIONS

Habitat networks depict the spatial structure of habitats and linkages between them, providing a comprehensive assessment of how single or multiple species use, or respond to, the spatial structure of their environment (Hobbs 2002, Opdam 2002). Thus, habitat networks confer multiple potential benefits to conservation planning and land management. First, different networks can be established and managed for different species or species groups, and potential differences and trade-offs in management strategies within and among groups can be assessed and reconciled. Second, network characterizations, by design, directly inform management actions to maintain, restore, or improve conditions for targeted species. Management strategies based on networks can be designed and implemented over several spatial and temporal scales, allowing priorities to be established in both time and space in relation to associated disturbance regimes. Finally, management strategies based on networks can be assessed and adjusted in relation to trade-offs between strategies developed for individual species, such as recovery plans for federally threatened or endangered species versus other policy or resource objectives (e.g., timber production, grazing, or recreation).

In the contrast to these benefits, management use of a habitat network may confer a sense of false confidence if information on which the network is based is insufficient to warrant its use. Knowledge of species' requirements is variable, and different species may respond differently to management at a given scale. Consequently, use of a network designed for multiple species, developed and implemented at a fixed scale, and with variable knowledge of requirements among the species represented in the network is likely to confer greater benefits to some species than others, and might not fully depict spatial patterns of importance for some species. These potential problems illustrate the necessity of an adaptive management approach when characterizing and implementing habitat networks (see "Implementing Habitat Networks Through Adaptive Management").

### Management Integration Within and Among Species Groups

The use of habitat networks for species groups does not limit the degree to which conditions for individual species can be assessed and managed. On the contrary, the concept of networks recognizes the inherent limits of time and resources to assess and manage conditions for individual species beyond a few special cases, and allows managers to take a more holistic approach when managing large landscapes for multiple species of conservation concern. Incorporating species groups in network design and comparing outcomes of group-based networks with those developed for individual target species can reveal how well strategies designed for groups support goals for individual species.

For large landscapes, different networks must be developed for different suites of species to accommodate the intrinsic biodiversity at this scale. That is, different species have different habitat associations, geographic ranges, and areas over which they conduct daily and seasonal activities in relation to the amount, distribution, configuration, and connectivity of habitats. Such differences mandate the use of multiple habitat networks, with each individual network designed to reflect conditions for species with similar habitat requirements and responses to habitat change.

## Direct Links to Management

Spatial information from habitat networks is intentionally derived to link directly with management for targeted species, and can help guide prioritization of management activities in space and time. In our case studies, past land management has profoundly affected the quantity and quality of habitats for species of concern. For example, in the Columbia Basin network, the dominant condition, i.e., Condition 3, for Families 1 and 11 represents suboptimal habitats, typically low-elevation sites that have been intensively managed for livestock, timber production, and other commodity uses. The preponderance of watersheds in Condition 3 exemplifies the urgent need to actively protect remnant habitats that still function effectively (i.e., those in Condition 1) and restore degraded or diminished habitats to improve connectivity among watersheds.

Often, initial development of a habitat network for management requires subsequent modification to address new or evolving management objectives. One example is the ongoing National Forest Plan revision process for three forests in eastern Washington state (Colville, Okanogan, and Wenatchee National Forests) (U.S. Forest Service 2006). To incorporate multispecies conservation strategies in the plans, the biologists modified the habitat network framework developed by Wisdom et al. (2002). To do this, the biologists selected focal species for analysis, including white-headed woodpecker (*Picoides albolarvatus*) and tiger salamander (*Ambystoma tigrinum*), and developed and applied Bayesian Belief Network models (Marcot et. al. 2001) for each species to estimate habitat suitability at the watershed level. Habitat suitability scores then were combined in a GIS with other attributes (e.g., amount of source habitat relative to historic median, land ownership pattern) to assign a habitat condition class to each watershed.

The resulting habitat condition classes then guided selection of a management strategy (e.g., restoration, protection, connectivity) for each focal species in each watershed. Overlays of networks for the focal species will guide prioritization of management through the application of conservation strategies to benefit multiple species. For example, one strategy is to reduce road construction and access in areas occupied by several focal species that are sensitive to effects of roads. The conservation strategies developed for the watersheds were created through an interdisciplinary process in order to address multiple resource objectives.

## Reconciling Network Strategies in Relation to other Objectives

A variety of laws, policies, and regulations guide resource management on state, federal, private, and tribal lands in the United States and elsewhere. Some of these directives clarify the need to maintain populations of all native biota in their native environments. For example, the U.S. Endangered Species Act dictates that no species will be managed so as to cause its designation as threatened or endangered. Similarly, regulations supporting implementation of the National Forest Management Act call for sustaining native ecological systems by providing conditions to support diversity of native plants and animals in the planning area (U.S. Government 2005). These regulations thus provide a clear basis for development and implementation of holistic approaches for species management, such as habitat networks.

Other laws, regulations, and policies, however, provide direction for resource objectives beyond maintenance of native biota. The U.S. Multiple-Use Sustained-Yield Act, for example, requires National Forests to be managed for a wide variety of commodities and uses, including timber, livestock, mining, water, and recreation. The resultant challenge is to ensure compatibility between management to maintain populations of native species and management for other, potentially competing resources.

One method to reconcile species management with other resource objectives is to map conditions for each set of resources, including a habitat network for species of concern, and use results to identify compatibilities and conflicts in strategies among all featured resources. Trade-offs among resource objectives can then be explicitly considered, and all resource objectives integrated.

In the Great Basin, watersheds with abundant habitat and low risk of habitat loss are likely to represent "habitat strongholds" for the associated species. Under these conditions, other resource uses such as grazing and mining operations may be compatible with habitat maintenance. By contrast, watersheds of low or moderate habitat abundance but high risk may warrant subordination of livestock grazing, energy extraction, and other conflicting uses to habitat preservation for targeted species of conservation concern.

These examples illustrate the degree to which spatial information about species of conservation concern can be represented by habitat networks for setting joint policies and strategies to concurrently meet a variety of management objectives among multiple stakeholders. In particular, the use of habitat networks to evaluate trade-offs among competing resource objectives, and to ultimately reconcile potential conflicts among these objectives, can be an essential component of multiple use management within and among all land ownerships in relation to a diverse array of laws and policies.

# FUTURE DIRECTIONS

## Knowledge Gaps

Concepts and uses of habitat networks will evolve as knowledge about networks is gained and applied. Currently, information needed to fully implement effective networks is limited for most species (Hobbs 2002). Fundamental knowledge to develop habitat networks is lacking for four key topics: (1) environmental requirements of individual species, in terms of number, distribution, and configuration of habitat patches; (2) size of and distance between habitat patches to best facilitate dispersal and other inter-patch movements; (3) resistance and resiliency of species' habitats given prevalent disturbance regimes; and (4) integration of the above information for multiple species. All four topics encompass issues of spatial and temporal scale, specifically how habitats and associated populations of species will be evaluated and maintained at the appropriate spatial and temporal extents (appropriate geographic area and time period for managing the species) and at the appropriate spatial and temporal grain (i.e., the resolution at which habitats and populations are measured and how often the measurements are taken). Traditionally, habitat networks have emphasized the first two topics, but the third and fourth are equally relevant for holistic conservation planning. Consequently, new research is required to address knowledge gaps about habitat networks and their application (see Hobbs [2002] and Opdam [2002] for additional review of knowledge gaps related to habitat networks).

For example, little is known about the environmental requirements of most species of conservation concern beyond birds and large mammals (Bonnett et al. 2002, Clark and May 2002), particularly in relation to the spatial configuration of habitat patches and their colonization potential (topic 1). Research needed to address this topic would focus on species occurrence and persistence in habitat patches that vary in size, configuration, vegetation structure and composition, landscape setting, and other environmental factors. Similarly, for most species, little is known about habitat connectivity and flow of individuals among habitat patches (Opdam 2002, Schulte et al. 2006) (topic 2). Species-level (i.e., fine-filter) research needed to address this topic would include studies of metapopulation dynamics, dispersal rates, movement behavior, use of corridors or other linkages, and optimal inter-patch distances.

Habitat networks are unlikely to remain stable over time. Disturbance agents such as wildfire, floods, drought, invasive species, and myriad human activities must be considered when planning for maintenance of habitat networks. It follows that the concepts of habitat resistance and resiliency should be addressed when planning and developing habitat networks (topic 3). If habitats lack resistance and resiliency, then larger habitat patches must be conserved to buffer against environmental stochasticity. Unfortunately, knowledge of habitat resistance and resiliency is limited, particularly in the face of global climate change and the increasing human footprint affecting habitats worldwide (Sanderson et al. 2002). Moreover, knowledge is lacking about species response time to habitat changes, or effects of shifts in habitat configuration on metapopulation dynamics (Opdam 2002, Frank 2004).

The potential for holistic integration of multiple species of conservation concern in habitat networks is seldom broached. Concepts of habitat networks initially addressed individual species and how they used geographically isolated habitat patches in fragmented landscapes. The metapopulation dynamics exhibited by these species provided a basis for designing habitat networks that were sufficiently connected to allow for interaction among individuals from different local populations. Applying networks for individual species, however, is an impractical approach to meet overarching goals of biodiversity conservation (Noss and Cooperrider 1994, Opdam 2002). The challenge now lies with understanding how metapopulation dynamics of many species of conservation concern can be considered comprehensively. This challenge is probably impossible to fully meet, given the multitude of species that typically deserve management attention in a single large landscape.

Integration of a comprehensive set of species' needs in network design and management can be approached with both top-down and bottom-up methods (Gripenberg and Roslin 2007). Top-down methods of research would attempt to elucidate spatial structure of populations of multiple species with similar environmental requirements, space use, and movements, without conducting detailed research about metapopulation characteristics of each species. By contrast, bottom-up methods would focus on how selected species of concern use habitats, relying on traditional metapopulation research techniques. Because this research is extremely costly and time-consuming, species selected for such detailed studies would ideally represent a larger set of species of conservation concern, using concepts such as focal species (Lambeck 1997).

## Implementing Habitat Networks Through Adaptive Management

Habitat networks and associated conservation planning serve as regional hypotheses that can be tested and evaluated through landscape-level management experiments under the auspices of adaptive resource management (Fig. 19-1; Walters 1986, Kendall 2001). Under the paradigm of adaptive management, research and management collaborate to identify knowledge gaps, especially those affecting key economic, social, political, and ecological issues. The collaborators then develop testable management hypotheses, followed by management experiments and implementation of results in land management. This cycle is repeated as necessary to identify additional knowledge gaps and improve outcomes of management. (See Haddad et al. [2003] for an excellent example of a broad-scale, manipulative experiment to evaluate corridor use by different taxa.)

If validation research, ideally applied through adaptive management, is not conducted to address primary sources of uncertainty associated with habitat networks, the utility and credibility of networks may be questioned. Consequently, such research is integral to fostering use of habitat networks in land management and conservation planning. A benefit of using an adaptive management framework is that managers have the freedom to design and implement habitat networks despite uncertainty about the networks and their efficacy in maintaining ecosystem diversity or protection for individual species.

Schulte et al. (2006) found limited and inconsistent application of habitat networks and other related concepts in planning for biodiversity. Despite obstacles to implementation of networks, however, land managers can learn much by incorporating habitat networks as part of standard operations for conservation planning and management. For example, under the 2008 final rule describing the future land management planning framework of the Forest Service, an environmental management system (EMS) will be required for land management planning throughout the agency (U.S. Government 2008). The EMS will serve as a framework for adaptive management in the Forest planning process; habitat networks offer one tool for assessing environmental conditions for multiple species on National Forest lands under such a framework.

Management use of habitat networks will be challenging, given existing knowledge gaps, limited resources, and diverse management objectives. However, the alternative—ignoring spatial structure of habitats—will ultimately lead to failure. That as context, we advocate increasing emphasis on management application of, and research focus on, habitat networks.

## SUMMARY

Powerful analysis tools now enable ecologists to characterize landscapes at a variety of spatial scales directly applicable to management. One such application is the use of habitat networks to characterize and manage large landscapes for habitats and species of interest. A habitat network is a spatially explicit portrayal of environmental conditions across large areas that can be used to understand the status and trends of wildlife species, particularly in relation to how species needs are met through management of habitat abundance and distribution. In this chapter, we discussed the concepts of habitat networks and provided case examples for two areas in the western United States: the Interior Columbia Basin and the Great Basin. To address the need for broad-scale, comprehensive planning within the Interior Columbia Basin, we developed a habitat network for five groups of terrestrial vertebrates. We used habitat abundance and habitat quality to describe watersheds in the 58 million-ha basin. Watersheds were assigned to one of three habitat condition classes for each species group. In a similar analysis, we mapped habitats for groups of sagebrush-associated vertebrates in the Great Basin. Here, we characterized watersheds for each species group by (1) habitat abundance, (2) habitat at risk of displacement by cheatgrass, and (3) the composite conditions of habitat abundance and risk. Mapping habitat networks can foster efficient conservation planning at regional levels by guiding the spatial prioritization of limited resources for habitat conservation and restoration. The methods we described can be augmented with additional spatial models that incorporate other landscape and ecological characteristics, such as habitat or population connectivity and land protection status. We discussed implications of mapping habitat networks in the context of current management and policies related to wildlife habitats, as well as future needs for characterizing wildlife habitats across large landscapes.

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