

Ex-urban development in the Rocky Mountain West : consequences for native vegetation, wildlife diversity, and land-use planning in Big Sky, Montana
by Lauren Marie Oechsli

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biological Sciences
Montana State University
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Abstract:
The inter-mountain west of the United States is the fastest growing region in the country in both population and per capita income. With growth and increased wealth come development and conversion of lands from natural habitats to urban and rural-residential landscapes, directly affecting native biotic communities. As habitat loss is the leading cause of species' extinction and endangerment, it is wise to assess habitat availabilities and roles in biodiversity prior to extensive land change or fragmentation. This study employed a GIS and aerial photographs to model potential species richness, determine the pattern and rate of development, and identify locations of potential conflict between biodiversity and future development in the Gallatin Canyon/Big Sky planning district of Gallatin County, Montana. Species distribution models from Montana Gap Analysis Project were used to classify potential habitat for vertebrate species and assess biodiversity via species richness. 'Hot spots' of richness were identified primarily along watercourses and at lower elevations. Analysis of building locations in relation to vegetation identified those habitats most often chosen for development. Low/moderate cover grassland, montane parkland & sub-alpine meadow, mixed xeric shrub, and riparian were used for development more than expected based upon availability, with low/moderate cover grassland accounting for the 81% of all impacted lands. Variables correlated with development were distance to roads, distance to streams, elevation, slope, aspect, percent conifer, percent riparian, percent rock, percent grass/shrub/meadow, grazing status, vegetation diversity, and neighborhood density. These predictors were used to calculate the Mahalanobis distances for lands in private ownership. The statistic assessed the multivariate similarity between attributes at any given location and the mean vector of attributes from all developed lands. Mapping the statistic identified undeveloped areas in the landscape that resemble developed areas and are, therefore, considered suitable for development. Locations most suitable for development occurred close to streams and at lower elevations, indicating that humans and a majority of wildlife species are competing for habitat. Locations where hot-spots of richness coincided with high suitability for development were identified, providing information useful to human communities wanting to make better-informed decisions regarding conservation, zoning plans, and open-space preserves.

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Lauren Marie Oechsli

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

The inter-mountain west of the United States is the fastest growing region in the country in both population and per capita income. With growth and increased wealth come development and conversion of lands from natural habitats to urban and rural-residential landscapes, directly affecting native biotic communities. As habitat loss is the leading cause of species' extinction and endangerment, it is wise to assess habitat availabilities and roles in biodiversity prior to extensive land change or fragmentation. This study employed a GIS and aerial photographs to model potential species richness, determine the pattern and rate of development, and identify locations of potential conflict between biodiversity and future development in the Gallatin Canyon/Big Sky planning district of Gallatin County, Montana. Species distribution models from Montana Gap Analysis Project were used to classify potential habitat for vertebrate species and assess biodiversity via species richness. 'Hot spots' of richness were identified primarily along watercourses and at lower elevations. Analysis of building locations in relation to vegetation identified those habitats most often chosen for development. Low/moderate cover grassland, montane parkland & sub-alpine meadow, mixed xeric shrub, and riparian were used for development more than expected based upon availability, with low/moderate cover grassland accounting for the 81% of all impacted lands. Variables correlated with development were distance to roads, distance to streams, elevation, slope, aspect, percent conifer, percent riparian, percent rock, percent grass/shrub/meadow, grazing status, vegetation diversity, and neighborhood density. These predictors were used to calculate the Mahalanobis distances for lands in private ownership. The statistic assessed the multivariate similarity between attributes at any given location and the mean vector of attributes from all developed lands. Mapping the statistic identified undeveloped areas in the landscape that resemble developed areas and are, therefore, considered suitable for development. Locations most suitable for development occurred close to streams and at lower elevations, indicating that humans and a majority of wildlife species are competing for habitat. Locations where hot-spots of richness coincided with high suitability for development were identified, providing information useful to human communities wanting to make better-informed decisions regarding conservation, zoning plans, and open-space preserves.

INTRODUCTION

Preservation of biological diversity is of great interest to conservation biologists, governments, and many citizens. Biological diversity is the "variety of life and its processes, including the variety of living organisms and the genetic differences among them, as well as the variety of habitats, communities, ecosystems, and landscapes in which they occur" (Likens 1992, quoted in Christensen et al. 1996). The interest in biodiversity is global, as evidenced by the existence of national and international organizations and legislation designed to protect it – e.g., The United Nations' Educational, Scientific, and Cultural Organization's World Heritage branch (UNESCO 1998), the European Union's Habitat Directive (Williams 1995), the U.S.'s Endangered Species Act (16 U.S.C. 1531-1544), and the National Gap Analysis Program of the USGS Biological Resources Division (Scott et al. 1993).

Recognizing that preserving biodiversity is an important challenge, the logical question follows, "What is the main threat to biodiversity?" The above groups all agree that the main threat to biodiversity is the loss and alteration of habitat, the leading cause of which is anthropogenic impact. Indeed, it has been suggested that in the U.S., the greatest number of endangered species occur in states where high levels of endemism coincide with intense anthropogenic activities such as agriculture and urbanization, i.e., California, Florida, and Hawaii (Dobson et al. 1997).

Concern over anthropogenic change often focuses on urban sprawl, typically a management concern for highly urbanized areas. When human growth threatens the last remaining open spaces or begins to have noticeable ill effects on nearby wildlands,

reactionary management is the common recourse. In response to loss of open space in the U.S., state and local governments have devised a variety of reactive and proactive coping mechanisms. For example, funds are actively raised by governments to purchase land and development rights (Daniels and Bowers 1997), new development is encouraged in previously established towns with extant infrastructure as opposed to rural areas, and aggressive growth-management systems designate urban growth boundaries and impose development restrictions (Moore and Nelson 1994; Daniels and Bowers 1997).

In highly urbanized areas, alteration of the landscape is apparent. However, development also degrades rural areas in a variety of ways. Growth of urban land-use (i.e., residential/commercial/industrial/public buildings, parking areas, and transportation) has been found to progress eight times faster than the growth of the human population, leading to a rapid change in a community's appearance (The American Society of Planning Officials 1976; LaGro 1994). Sprawling and second home developments can be an economic burden, as they often do not contribute the additional tax base needed to support schools and infrastructure improvements (The American Society of Planning Officials 1976). Environmental impacts can cause recreation and tourism dependent communities to lose those assets that formerly contributed to their economic stability (Rasker 1994). Resort communities, especially prone to escalating property values and cost-of-living, often evolve into towns whose full-time residents can no longer afford to stay (Culbertson et al. 1992; Gill 1992). Wildlife species sensitive to disturbance retreat to more remote areas (e.g., Mace et al. 1996), while some animals are killed due to interactions with humans. Scenic beauty is compromised as hillsides are marked by

homes and roadways, and the ecological health of the area often declines (The American Society of Planning Officials 1976; Gill 1992; Meyer and Turner 1992).

Impacts of urbanization on wildlife from different taxa have been documented across the entire urban gradient, from low-density rural areas to urban centers (e.g., Blair 1996; Bowers and Breland 1996; Blair and Launer 1997; Harrison 1997; Gering and Blair 1999). At moderate levels of development, diversity of certain avian communities increases. This increase is partially due to the influx of generalist, exotic, and urban-adaptable species at the expense of specialists and non-adaptable natives (Blair 1996; Germaine et al. 1998). Higher levels of development, however, cause a decrease in both total and native species diversity (Blair 1996). Some, but not all, generalists benefit from anthropogenic alteration. Large carnivores such as wolves and grizzly bears tend to require vast amounts of relatively undisturbed habitat. Fragmentation and habitat conversion make fulfilling this need progressively more difficult (Mattson et al. 1987; Mech et al. 1988; Mladenoff et al. 1995; Mace et al. 1996). Other development effects can be more subtle. Manicured lawns (Racey and Euler 1983), low-level traffic (Mader 1984), and the presence of bird feeders and pets (Bowers and Breland 1996) can effectively increase the cumulative disturbance effect that low-density developments have on mammal communities. Additionally, vegetation changes can alter microclimate (Mader 1984), habitat structure (Blair and Launer 1997), and, consequently, invertebrate communities.

Given that habitat loss and alteration resulting from anthropogenic land-use threaten the biodiversity that many are trying to preserve, how will we reconcile rapid growth and development of human societies with the desire to preserve biodiversity?

Reconciliation will likely require adoption of a landscape-level, interdisciplinary approach that incorporates biology, ecology, agriculture, sociology, economics, and urban planning with the aim of developing proactive land management tools. A useful tool would analyze biodiversity, development patterns, and the ways in which they interact (McDonnell and Pickett 1990) such that the information provided could help direct conservation and planning processes. The aim of this project is to develop such a tool.

The intermountain west of the United States is experiencing a range of developmental impacts due to expanding human populations. As a whole, the region lies toward the rural end of the urban gradient, however, human/nature conflicts are becoming apparent. The region is one of the fastest growing in the country in both population and per-capita income (Riebsame 1997), and counties with recreation or retirement communities are growing faster than other rural or metropolitan areas (Anonymous 1994; Johnson and Beale 1994). People are drawn to rural, mountain regions of the west for many reasons, which may be summed as 'quality of life' (Rudzitis and Johansen 1989; Howe et al. 1997). However, increasing human populations threaten the features that attract people to the region (The American Society of Planning Officials 1976).

The Gallatin Canyon/ Big Sky planning district of Gallatin County, Montana, is an ideal location for a case study of the pattern of urbanization and its impact on habitats and species in the intermountain west. The area is representative of other rapidly growing towns in the region, where natural assets and a high quality of life might be affected by an influx of people. Wildlife and scenic beauty are abundant, while skiing, snowmobiling, hiking, fishing, and hunting are just some of the recreation opportunities

available year-round. Though the growth rate is high, the level of development is still low on the urban gradient allowing the area to benefit from foresight in land planning. Accordingly, I developed this study to aid interdisciplinary management by providing information on potential vertebrate habitats, biodiversity, and the impact of past and potential future development on vegetation types and species distributions. Specific objectives of the study were,

(1) Use species-habitat models developed by the Montana Gap Analysis Project (Hart et al. 1998) to estimate potential distributions for vertebrate species and obtain species richness measures for the study area,

(2) Quantify the rates, spatial location, and impact of human development on vegetation types and potential species distributions from 1962 to 1998,

(3) Use associations between locations of human development and environmental variables to identify preferred development sites, and

(4) Explore the implication for future conservation, research, and land planning efforts as they relate to species richness.

The results of this study might prove useful to other developing mountain towns in the Greater Yellowstone Ecosystem and the intermountain west, as the information generated might have significant application for groups interested in sustainable management.

Information on vertebrate species distributions and habitat associations can be gathered in a variety of ways, at a variety of scales, and for single and multiple species. In addition to environmental variables, each available technique requires additional species information of varying complexity. Expert-systems models (wildlife-habitat relationships or habitat suitability indices) require compilation of habitat affinities

gathered through literature search and expert opinion (Verner et al. 1986; Scott et al. 1993; White et al. 1997). The multivariate Mahalanobis statistic (Clark et al. 1993; Knick and Dyer 1997) and an optimal habitat approach developed for a GIS (Dettmers and Bart 1999) require field data on species presence locations only. Overlap analysis (Brito et al. 1999), a simplified GIS method, requires presence and absence data for each modeled species. Other, more statistically rigorous, models also require data on species presence, absence, and/or abundance – linear regression (Morrison et al. 1987; Iverson and Prasad 1998), logistic regression (Pereira and Itami 1991; Mladenoff et al. 1995, Nadeau et al. 1995; Brito et al. 1999), and multivariate methods – principle components analysis (Debinski and Brussard 1994), canonical correspondence analysis (Blair 1996), classification and regression tree analysis (O'Connor et al. 1996), and discriminant function analysis (Mosher et al. 1986). At the most complex, spatially-explicit demographic models (Noon and McKelvey 1992; Lamberson et al. 1994) require detailed data on vital rates, habitat selection, home range, edge effects, density effects, competition, and other factors.

Though expert-systems models are not based on statistical methods (Dettmers and Bart 1999) and cannot incorporate spatial dynamics of interaction between animals and their habitats (Turner et al. 1995), they do have advantages over the other techniques that require a substantial amount of presence/absence data to build and test models. Typically, these data are acquired via an extensive field survey of the study area and focus on one species or an assemblage of species from one taxonomic class. When biodiversity is the focus, it is desirable to analyze a wider range of species, given that areas harboring large numbers of different species (hotspots of species richness) might

not coincide for different taxa and that rare species might not be found in any hotspot (Prendergast et al. 1993; Harcourt 1999). Collecting field data for many species requires time and economic investment. Expert-systems models, on the other hand, can be generated for many species from different classes with reasonable investment. These models are typically generalized for application across a broad geographic area, allowing them to be employed by a variety of users. Though simplistic compared to the more rigorous, statistical methods, expert-systems models incorporate findings from previous field studies, as well as the cumulative knowledge of professionals. Additionally, when many species of interest are either wide-ranging or generalists, even a large amount of field data might not result in a statistical model with higher predictive ability than an expert-systems model.

Combining information on species habitats and richness with information on the pattern of human development can greatly enhance conservation efforts by identifying species and habitats most at risk of anthropogenic impact. Municipal records, or more commonly remotely sensed data of the same area at different time points, can provide source information for assessing land-cover change and impact (Wear and Flamm 1993; Thibault and Zipperer 1994; Turner et al. 1996). Studies of land-cover change and urbanization have identified several variables associated with development: ownership, slope, elevation, distance to roads or markets, population, position on urban gradient, and neighborhood density (Wear and Flamm 1993; Turner et al. 1996; Poudevigne et al. 1997; Wear et al. 1998; Maxwell et al. 2000). While slope, elevation, distance to road and market, and presence of other buildings (and infrastructure) might account for some of the economic drivers of development, a biological reality is that human development is

also tied to water availability. It is likely, therefore, that vegetation types and species occurring in close proximity to water and roads, at lower elevation, and on more level ground have been and will continue to be impacted by development to a greater degree than others, causing them to be at greater risk of local extinction. Assessing the pattern of past development, therefore, is a useful method for predicting where future development might occur, thereby allowing concerned communities to influence where it will occur (Alig and Healy 1987; Wear et al. 1998).

STUDY AREA

The study area was the Gallatin Canyon/Big Sky planning district of Gallatin County in southwestern Montana (Figure 1: NW corner 470776 m, 5021966 m; SE corner 496930 m, 5002291 m; UTM; Zone 12). The county planning department was responsible for establishing zoning ordinances within the planning district. The study area was 53,195 ha and contained portions of the Gallatin and Upper Yellowstone River watersheds, portions of the Gallatin and Madison mountain ranges, and a section of the Lee Metcalf / Spanish Peaks Wilderness unit. The environmental conditions of the district were spatially highly variable. Elevation ranged from 1,750 m – 3,200 m. The lowest elevations in the study area were dominated by shrub/grass communities and Douglas-fir (*Pseudotsuga menziesii*). The predominant vegetation in the study area was lodgepole pine (*Pinus contorta*), while the treeline community was dominated by sub-alpine fir (*Abies lasiocarpa*), Englemann spruce (*Picea engelmannii*), and whitebark pine (*Pinus albicaulis*). Rock and alpine meadows existed above the treeline. Riparian communities were associated with the many streams found in the district. The climate was dry and temperate. Mean annual precipitation was 0.49 m while mean annual snowfall was 3.5 m; mean minimum/maximum temperatures were -14.7/-1.6°C and 3.6/25.6°C for the coolest and warmest months respectively (years 1984-2000; Western Regional Climate Center 2000). A wildlife assessment of the area suggested potential for the presence of ~200 species of amphibians, reptiles, birds, and mammals (Picton 1976). The Montana Gap Analysis Project suggested the number might be closer to 350 (Hart et al. 1998). The area was settled by European Americans as recently as 1898, with a low

human population until the Big Sky Resort, a destination ski resort that also attracted summer use, was established in 1969 (Cronin and Vick 1992). The resort has brought increasing levels of tourism to the area as well as a growing resident community. Urbanization of the district was restricted to 12,500 ha of private inholdings found throughout the public lands, which were under the stewardship of the USDA Forest Service.

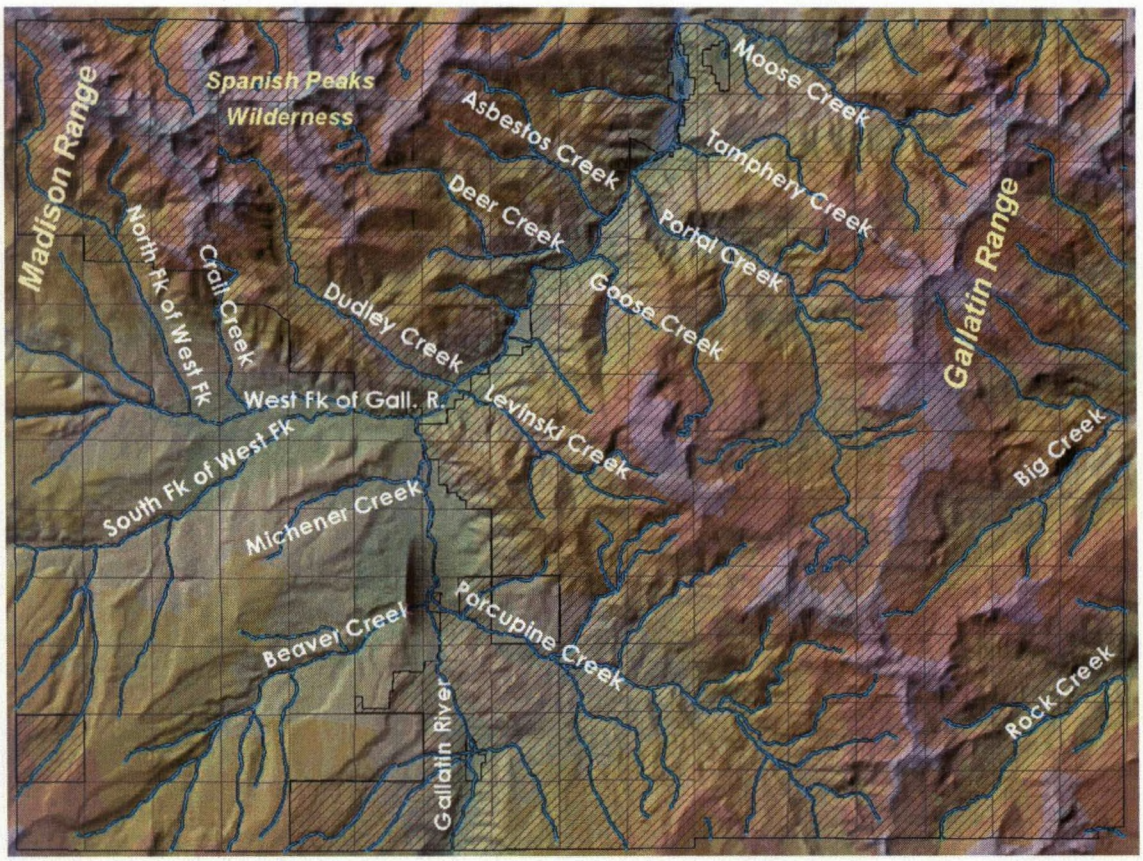


Figure 1. Study Area. Shaded-relief map of the Gallatin Canyon/Big Sky Planning District with stream names labeled. Hashed area represents public lands. Light grid identifies the township/range sections that comprise the planning district.

METHODS

Overview

After an extensive phase of data acquisition and manipulation (Appendix A), three methods were used to meet the outlined objectives. First, species-richness maps were produced through the application of Montana Gap Analysis Project's species-distribution models to GIS data layers. Second, development impacts were quantified within a GIS by overlaying urban areas with a native vegetation data layer and analyzing areas of intersection. Third, conflict between potential future development and biodiversity was identified by first creating a statistical model that assessed suitability for development on all private lands, then overlaying this suitability map with a species-richness map.

Available Data Sources

Extant data layers were obtained for elevation and streams (abiotic layers); county boundary and sections (political layers); roads and grazing status (anthropogenic layers); and vegetation (biotic layer). Elevation data came from a USGS 30-m digital elevation model (DEM). Stream data, county boundary, sections, and roads were all acquired from the Gallatin County GIS Department in vector format. The grazing layer (vector format) classified land as grazed or not grazed and was acquired from Gallatin County GIS Department.

These basic data layers were used to create four additional layers needed for modeling species distributions, assessing development suitability, or both. Arc/Info (E.S.R.I. Inc. 1998) software and the DEM were used to generate 30-m raster-format layers of slope in percent rise and aspect in degrees. Concentric buffers in 30-m increments were calculated around both the roads and streams line data until all land within the study area fell within a buffer. In this way, the distance from any given point to the closest road or stream could be determined (within 30 m) by the distance associated with the buffer containing that point. Increments of 30-m were chosen to agree with the resolution of the DEM.

Modeling and GIS analyses can become complex when different sources of vector data with unique polygon boundaries are intersected due to the resulting large number of unique combinations. Therefore, I converted all vector data layers that would be used in later analyses to 30-m raster data layers using the GRID module of Arc/Info. Certain data were used only for display purposes (county boundary, sections, roads and streams) and were therefore not converted to raster format. The 30-m cell size was originally chosen to correspond with that of the DEM.

Vegetation Data and Accuracy Assessments

Vegetation data were acquired as two separate data sets, one for the Madison Range and one for the Gallatin Range. These data were generated from the USDA FS Timber Stand Management Record System. They were digitized in vector format at either 1:15,840 or 1:24,000 scales by the USDA FS between 1994 and 1996. I first

merged these two vegetation layers along their common border to create one coverage (VEG). Data on ownership were originally contained in VEG such that each vegetation polygon was assigned an ownership category, Forest Service or non-Forest Service. For ease of manipulation, the ownership data were extracted from VEG to create a new layer (OWNER), which was then generalized to remove unnecessary polygons (i.e., two adjacent polygons with identical ownership categories were merged into one polygon).

Within the VEG layer, the cover type "civil" represented areas that the USDA FS considered developed. For analyses of developmental impacts on vegetation, I created a pre-development vegetation layer that represented native vegetation as opposed to the civil cover type. To do this, I reclassified those polygons labeled as civil into appropriate USDA FS native vegetation classes via aerial photograph interpretation using 1:24,000 scale aerial photos from 1962. This year was chosen because it preceded the major development boom in the area, and complete aerial coverage existed for this year. Each polygon labeled civil was located on the 1962 photographs, and the vegetation in that and the surrounding polygons was examined. If the vegetation could not easily be distinguished, the labels of the surrounding polygons were used to help classify the vegetation type. For example, if a polygon had been converted from conifer forest to civil, but I was not sure if it had been Douglas-fir or lodgepole pine, I consulted the VEG layer classification for the surrounding conifer forest to help re-classify the polygon to native vegetation. The reclassification created a new data layer, VEG62.

For the purpose of modeling species distributions, the 33 USDA FS cover types present in VEG/VEG62 were re-coded into 20 cover types agreeing with those used by the Gap Analysis Project (Appendix B). The reclassification resulted in two additional

vegetation data layers, VEGGAP and VEGGAP62. As with the other vector data sets, all vegetation layers were converted to 30-m raster format for use in modeling.

Because these vegetation data were integral to modeling species distributions, as well as to many of the other objectives of this study, a validation effort was undertaken to quantify their accuracy. To assess the categorical accuracy of VEG (the original USDA FS categories) and VEGGAP (the re-coded GAP categories), I randomly chose 109 polygons from the original vector dataset. These polygons were identified on aerial photos and topographic maps, then located in the field. Cover type of each located polygon was recorded, and error matrices were constructed for both USDA FS and GAP classifications.

Error matrices compare the classified category to the true category of a datum. The columns of the matrix represent the "true" categories and the rows the "classified" categories. When the matrix cells are filled with the sample information, the correctly classified samples fall on the diagonal and the incorrectly classified samples on the off-diagonals (Congalton 1991; Janssen and van der Wel 1994). Overall accuracy refers to the total number of sample polygons correctly classified (on-diagonal) divided by the total number of samples field verified (Congalton 1991). Two additional measures of accuracy are omission error and commission error. Commission attempts to measure how well each category, as classified, captures the truth, while omission attempts to measure how well each true category has been represented by the classification (Janssen and van der Wel 1994). For example, an error of commission occurred for the classified (digital) lodgepole pine category when a polygon that was truly Douglas-fir was included in the lodgepole category (Table 1 – Results). An omission error occurred for the true

(on-the-ground) lodgepole category when a polygon that was lodgepole pine was omitted from that classification, for instance, misclassified as Sub-alpine fir (Table 1 – Results). In the error matrix, errors of omission fall on the off-diagonal within columns, while the errors of commission fall on the off-diagonal within rows. For this study, errors of commission and omission were identified, but small sample sizes within categories precluded interpretation. Another means of measuring overall accuracy, while taking omission and commission into account, is Kappa analysis. This analysis also was conducted because it results in a value (Khat) that is more appropriate for comparing the accuracy of classifications (Congalton 1991)

The spatial accuracy of the VEG data layer was also assessed. Established methods for spatial accuracy assessment predominately relate to the calculation of a root mean square (RMS) value. RMS measures the agreement in x and y directions between georeferenced imagery and ground control points (Janssen and van der Wel 1994). This methodology was not directly applicable to the assessment needed in this study. Instead, I wanted a measure in both x and y directions of the spatial agreement between the VEG data and the orthophotographs because these data would later need to be integrated (Figure 2). To quantify the spatial agreement, a second random sample of 307 polygons was chosen from the VEG layer. Of these, it was possible to identify distinct boundaries on the orthophotographs for 110 polygons. It was important to use only polygons with distinct boundaries to minimize error during the subsequent on-screen digitizing. Because polygons were made of vertices linked together by a continuous line, coordinates for the vertices from the sample polygons were extracted. Coordinates were pooled for each group; VEG layer polygon vertices and orthophoto-derived digitized

polygon vertices (Figure 2). The mean coordinates of the two groups were then compared in both the x and y directions using t-tests.

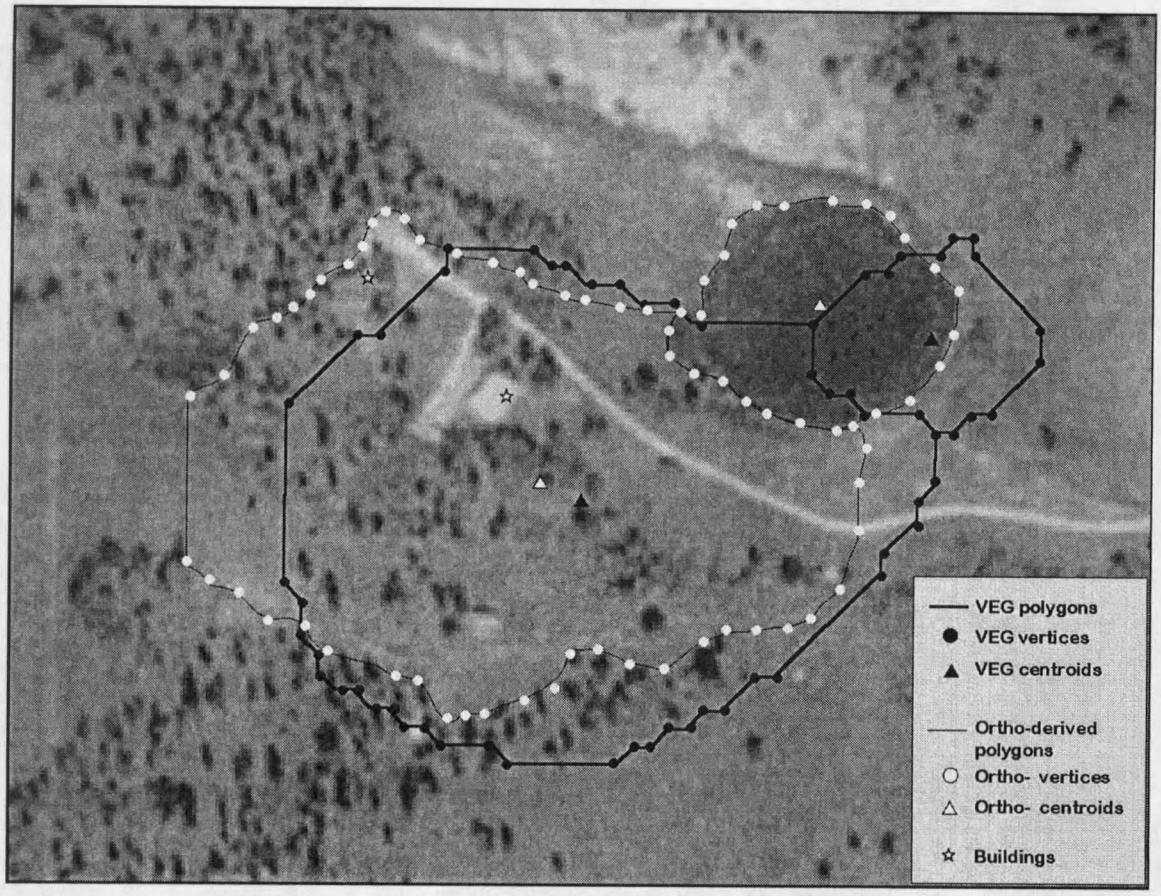


Figure 2. Spatial Accuracy Assessment Methods. Orthophotographs were used as source data to on-screen digitize 110 sample polygons used to assess the spatial agreement between VEG polygon boundaries and orthophotographs. Building locations were also digitized using the orthophotographs as source data.

Because only the polygons of the two groups were paired (individual vertices were not paired), I used the x and y coordinates of the polygon centroids (geographic centers) to assess the extent of the spatial discrepancy to determine an appropriate buffer distance to apply to all building point locations (Figure 2). Histograms of the differences between centroid locations of the 110 polygon pairs were plotted to determine an

appropriate buffer distance for the building point locations. Using this methodology, true ground accuracy of the VEG data layer was not quantified. Rather, the orthophotographs were used to represent the truth to which the VEG layer was compared. This was done because the orthophotographs were the data source used to identify and digitize building locations (Figure 2), and these building locations would be used to identify correlates of development and create a prediction model for future development. For example, if there was a spatial discrepancy between the orthophoto-derived building layer and the VEG layer, overlaying the two in an attempt to identify a correlation between building locations and vegetation type could create erroneous results if building locations fell into the incorrect vegetation polygons.

Urbanization Data

In addition to the above layers, I created a dataset of all building locations in the study area using six orthophotographs in 7.5-minute quadrangle format. Three 2-m resolution orthophotographs covering the southern portion of the study area were generated by the USDA FS in 1995. Three orthophotographs covering the northern portion were created by a private remote sensing company at 5-m resolution in 1998. The orthophotographs were used in the GIS as the source data for on-screen digitizing of building locations into vector format point data. Although resolutions of 5 m or less are thought adequate for mapping urban areas (Konecny et al. 1982), a validation of the building dataset was undertaken mainly to ensure that the different resolutions of the orthophotographs did not affect the accuracy of identifying building locations. Maps of

building locations were printed and taken to the field for spot-checking. I traveled to all locations of individual buildings in remote areas to ensure that these were indeed buildings. Buildings within established communities were checked less thoroughly because they were more confidently identified at both resolutions. During the course of the building field check and the vegetation validation effort, all maintained roads in the study area were censused for new buildings not on the orthophotographs. When encountered, these additional data were marked on maps and later added to the digital database. It was assumed that the majority of new buildings would have been close enough to established roads that they would have been identified. In this way, the final building-location dataset approximated the state of development at the end of 1998.

Re-Scaling

After the accuracy assessment of the spatial agreement between the VEG data layer and the orthophotographs (110 pairs of polygons), it was determined that a cell size of 150m for all data layers was necessary to accommodate the spatial discrepancy. The building-location point data were converted to raster format by dividing the study area into 150-m cells, each assigned a value representing the density of buildings (bldg/ha) within that cell. This building density layer was used to create a neighborhood density layer, wherein each cell was assigned the density value (bldg/ha) of the 9-cell neighborhood of which it was the center. The 30-m raster data (elevation, slope, distance to streams, and distance to roads) were generalized to the coarser resolution by the MEAN method – taking the average value from 25 30-m cells and assigning that average value to the new 150-m cell. Because aspect was a circular variable recorded in degrees,

I used Arc/Info and the re-sampled 150m DEM to create the 150-m raster layer for aspect (in degrees). Categorical data (soils, grazing, and ownership) were generalized by the MAJORITY method – assigning the new 150-m cell to the category that was most common in the 25 30-m cells.

The vegetation data layer, VEGGAP62 was treated differently than the other categorical layers when re-sampling from 30-m to 150-m cell size. Because some cover types, such as riparian, tend to occur in small or linear patches, the MAJORITY method might cause many of these patches to be lost in the aggregation of 30-m cells to 150-m cells. To avoid this, I calculated the percent of each 150-m cell accounted for by each cover type (by counting the number of 30-m cells of each cover type within the 150-m cell and converting to percent) and assigned these percentages to that cell. In this way, none of the information contained in the 30-m raster data set was lost.

The 30-m VEGGAP62 data were used as the source data to create a 150-m raster data layer called vegetation diversity. This layer is a measure of vegetation-type complexity and was created using the FOCALVARIETY command in GRID. This command calculated the number of unique vegetation types in the 25 30-m cells and assigned this number to the appropriate cell in the new VEG_DIV data layer.

Modeling Potential Habitat and Species Richness

The first specific objective of this study was to model potential species distributions and create measures of species diversity for the study area. To accomplish this, I first developed a list of all non-fish vertebrate species that could potentially exist in the study area (Appendix C -- Heath 1973; Picton 1976; Thompson 1982; Bergeron 1992;

Cramer 1992; Hart et al. 1998). To better represent the vertebrate community most likely utilizing the study area, I created a subset of the inclusive list wherein species were included only if there was strong evidence of existence in the Bozeman latilong (Appendix C). I then employed expert-systems models developed by the Montana Gap Analysis Project (Hart et al. 1998) to predict suitable habitat for individual vertebrate species, which I considered potential distributions. The potential distribution of each species was modeled by applying the Gap Analysis Project models to the necessary data layers in their 30-m raster format. Each species' model required one or more of the following data layers: land cover, percent canopy closure (an attribute of the vegetation layer), elevation, aspect, slope, distance to stream, and buffer zones around given vegetation types, and resulted in a map of potential distribution for the species (cells suitable for occupation coded as 1 and unsuitable coded as 0).

Overlaying and summing maps of all individual species yielded a measure of potential overall species richness where cell values represented the number of different species that could occur in a cell. Both lists, inclusive and the subset, were used to create species richness maps such that any differences in richness patterns could become evident. Species richness measures by class (amphibia, reptilia, aves, and mammalia) and special concern status (Appendix C), as determined by Montana Natural Heritage Program (2000), were also compiled. These maps were also re-created using only the subset of species most likely to exist in the study area. To assess the potential change in richness due to conversion of native vegetation to urban cover type, species models were re-run using the pre-development vegetation layer (VEGGAP62) and summed as before. To produce a more interpretable measure of change, the inclusive, overall current

richness map was then subtracted from the inclusive, pre-development richness map to quantify the estimated net change in potential richness.

Rates of Urbanization and Impact on Vegetation

The second specific objective of this study was to quantify the rates, spatial location, and impact of human development on vegetation types and potential species distributions from 1962 to 1998. Quantifying the rates and spatial locations of urbanization required that maps representing a time series of development be created from the original building-location point data. These data represented the state of urbanization in 1998. Aerial photographs were obtained from 1995, 1981, 1971, and 1962. Starting with the 1998 data layer, building locations were checked against the aerial photographs. If a building was not present at the time of the photograph, it was deleted from that year's data layer. In this way, map data layers were created for each of five time points: 1962, 1971, 1981, 1995, and 1998. The numbers of buildings at each time point were then used in a log-linear regression to assess the annual rate of development (Neter et al. 1996). Though a standard linear regression provided an estimate of the annual growth rate in buildings per year, the log-linear regression provided the instantaneous growth rate in percent, which allows for direct comparison to other growth rates.

Quantifying the developmental impacts on vegetation employed the re-coded vegetation layer (VEGGAP) and the vegetation layer representing the pre-development scenario (VEGGAP62), each in 30-m raster format. The area was calculated for each vegetation type in VEGGAP62 that had been converted to the urban category (the GAP

equivalent of the USDA FS civil cover type) in VEGGAP. Additionally, the total area of each vegetation class available for development was calculated—that is, area within private ownership. Excluding public lands from the available class assumed relative stability in the public land holdings. During the course of this study, several sections of land were affected by a land swap when they were converted from private to public ownership. However, because these sections were available for development while the majority of the buildings in the study area were constructed, I included them as available. The number of cells of each vegetation type that were available and that were converted were used in exact binomial tests to assess whether or not humans were choosing to build in certain vegetation types more or less than would be expected based on the amount of each vegetation type available in the study area (MathSoft, Inc. 1999). The test requires that there be a count of greater than five within each available category. To satisfy this, three cover types were combined into a riparian category: conifer riparian, graminoid and forb riparian, and shrub riparian.

Potential Future Urbanization and Conflict Avoidance

To assess any given cell's suitability for being developed, the attribute values of that cell were compared to a multivariate average value of the cells with buildings. This was accomplished by calculating the Mahalanobis distance statistic for each unused cell. The calculation requires a mean vector of variables from used (or presence) cells ($\hat{\underline{u}}$) and an estimated covariance matrix ($\hat{\Sigma}$), both of which were calculated using S-Plus software (Clark et al. 1993; Knick and Rotenberry 1998; MathSoft, Inc. 1999). The Mahalanobis

distance statistic is of the form

$$\text{distance} = (\underline{x} - \hat{\underline{u}})' \ \hat{\Sigma}^{-1} (\underline{x} - \hat{\underline{u}})$$

where $\underline{x}$ is a vector of variables associated with an unused cell (Clark et al. 1993). This statistic was a multivariate measure of the similarity between each unused cell and the mean vector of variables from cells with positive building densities. A random sample of 100 cells with buildings was excluded from the multivariate mean and covariance calculations for later use as validation data.

If data are distributed multivariate normal, the Mahalanobis distances are distributed approximately Chi-square having n-1 degrees of freedom (n = the number of predictors). This characteristic allows them to be re-coded into *p*-values that represent the probability of arriving at that distance statistic if the mean vector represents ideal conditions (Clark et al. 1993). In this study, the data were not distributed multivariate normal precluding the interpretation of *p*-values as probabilities. Instead, I re-coded the Mahalanobis values into 20% quantiles of all distances to rank the cells relative to the statistical description of used locations (Knick and Dyer 1997; Knick and Rotenberry 1998).

Before employing the Mahalanobis statistic, I needed to first identify correlates of development that would be used as predictors. For these analyses, I used the building-density data layer as the response variable and all potential predictor data layers (in their 150-m raster format). The VEGGAP62 data were used in the percent cover type form. However, because categorical data were converted to indicator variables, I condensed the categories in that dataset from 20 to 7 to reduce the number of predictors in the model

(grass/shrub/meadow, deciduous, conifer, water, riparian, rock, and alpine meadow). Aspect (a circular variable recorded in degrees) was transformed into a categorical variable: N, S, E, and W. Any cell with at least one building (421 cells) was used to represent an area of human use. A random sample (976 cells) of all cells in private ownership was selected to represent lands available for human use. For each cell, values of all variables were extracted from the GIS data layers. These data were then used as input for t-tests if the predictor variable was continuous: elevation, slope, distance to streams, distance to roads, and neighborhood density. Rank-sum tests were used if the predictor was categorical: all percent cover types, grazing status, aspect, and vegetation diversity. For both groups of tests, the α-level was set at 0.1 but was adjusted to test the family-wide significance of each *p*-value using the Bonferroni technique (Rice 1990). The more conservative α-level was chosen to ensure that all useful predictors (those with significant *p*-values for differences in means or medians) were included in further analyses (Knick and Dyer 1997).

Because small Mahalanobis values indicated a strong similarity in variable attributes between a given location and those locations with buildings, I defined suitable sites of future development as areas that had a Mahalanobis value in the top 20% of smallest values (Mahalanobis values ≤ 15), indicating a higher similarity to presently developed locations. Mapping distance values identified the spatial distribution of suitable development sites. Finally, the map of Mahalanobis values was intersected with maps of overall species richness, class-level richness, and species of special concern (for both inclusive list and subset) to identify places where high richness and high suitability for development coincide. These locations were considered areas of potential conflict.

RESULTS

Overview

For this study, I assessed the spatial patterns of species richness and development, quantified the rate and impact of past of development, identified sites that might be targeted for future development, and highlighted areas in the landscape that might represent a conflict between future development and species richness.

Vegetation Data and Accuracy Assessments

Error matrices from the categorical accuracy assessment showed that the vegetation classifications created by the USDA FS (VEG), and the subsequent re-classification into Gap Analysis Project categories (VEGGAP), were comparable in accuracy. Error matrices for the VEG and VEGGAP data resulted in estimates of 87% and 88% overall accuracy, respectively (Tables 1 & 2). The Kappa coefficients (Khats) showed accuracies for the USDA FS and GAP classified maps of 85% and 86% respectively, and were not significantly different from one another ($p > 0.05$). T-tests comparing the spatial agreement between polygon vertices from VEG and the orthophotographs showed differences in both the x and y directions ($n_{(VEG)} = 47968$, $n_{(ortho)} = 49686$, VEG $\bar{x} = 482487$, ortho-derived $\bar{x} = 482682$, $p < 0.001$; VEG $\bar{y} = 5012392$, ortho-derived $\bar{y} = 5012262$, $p < 0.001$). These t-tests were performed under the assumption of unequal variance after data for both x and y directions failed Levene's homogeneity of variance test at $\alpha = 0.1$ ($p = 0.083$ for x; $p < 0.001$ for y). Histograms

	DF	KR	LP	LPDF	SAF	WB	AV	Civil	Cliff	F	G	M	R	S	H_2O	Row Total	Commission Error (%)
Douglas-fir (DF)	21		2	1	1											25	16
Krumholtz (KR)		1														1	0
Lodgepole pine (LP)	1		22													23	4
LPDF Mix (LPDF)				3												3	0
Sub-alpine fir (SAF)	1		1		20											22	9
Whitebark pine (WB)					2	8										10	20
Avalanche (AV)				1												1	100
Civil								2								2	0
Cliff									1				1			2	1
Forb (F)														1		1	100
Grass (G)											7		1			8	13
Marsh (M)						1										1	100
Rock (R)													6			6	0
Sage (S)														2		2	0
Water (H_2O)															2	2	0
Column Total	23	1	25	5	23	9	0	2	1	0	7	0	8	3	2	109	Overall Accuracy 87%
Omission Error (%)	9	0	12	40	13	11	NA	0	0	NA	0	NA	25	33	0		

Table 1. Error Matrix for USDA FS Cover Type Classification of 109 Sample Polygons. Row names represent the cover type as classified in the digital USDA FS vegetation coverage (VEG). Abbreviations in parentheses correspond with column headings, which represent the true, on-the-ground cover type determined from field validation. For each on-the-ground category, an omission error occurs when a polygon is omitted from the correct classification. For each classified category, a commission error occurs when a polygon is included in the category but should not have been. Overall Accuracy refers to the total samples correctly classified (on-diagonal) divided by the total number of samples. Darkened cells correspond with error examples in text.

	4212	4203	4223	4270	4260	1100	3150	3170	8100	6200	7300	3300	5000	Row Total	Commission Error (%)
Douglas-fir (4212)	21	2	1	1										25	16
Lodgepole pine (4203)	1	22												23	4
Doug-fir/Lodgepole (4223)			3											3	0
Mixed Sub-alpine fir (4270)	1	1		20	1									23	13
Mixed Whitebark pine (4260)				2	8									10	20
Urban (1100)						2								2	0
Low-mod cover grass (3150)							3							3	0
Mod-high cover grass (3170)								3			1			4	25
Alpine meadows (8100)									2					2	0
Forb riparian (6200)					1									1	100
Rock (7300)			1								8			9	11
Mixed xeric shrub (3300)												2		2	0
Water (5000)													2	2	0
Column Total	23	25	5	23	10	2	3	3	2	0	9	2	2	109	Overall Accuracy 88%
Omission Error (%)	9	12	40	13	20	0	0	0	0	NA	11	0	0		

Table 2. Error Matrix for GAP Cover Type Classification of 109 Sample Polygons. Row names represent the cover types as re-coded into GAP categories in the digital vegetation coverage (VEGGAP). Codes in parentheses correspond with column headings which represent the true, on-the-ground cover type determined from field validation. For each on-the-ground category, an omission error occurs when a polygon is omitted from the correct classification. For each classified category, a commission error occurs when a polygon is included in the category but should not have been. Overall Accuracy refers to the total samples correctly classified (on-diagonal) divided by the total number of samples.

of the differences of paired centroids (in x and y directions) showed that a margin of 150m (+/- 75m) would encompass 100% of the differences in x direction and 90% of the differences in y direction (Figure 3). This effective buffer distance was incorporated into further analyses by choosing a 150-m cell size when converting point and vector data to raster data. Similarly, all raster data available at finer resolutions were aggregated to this cell size.

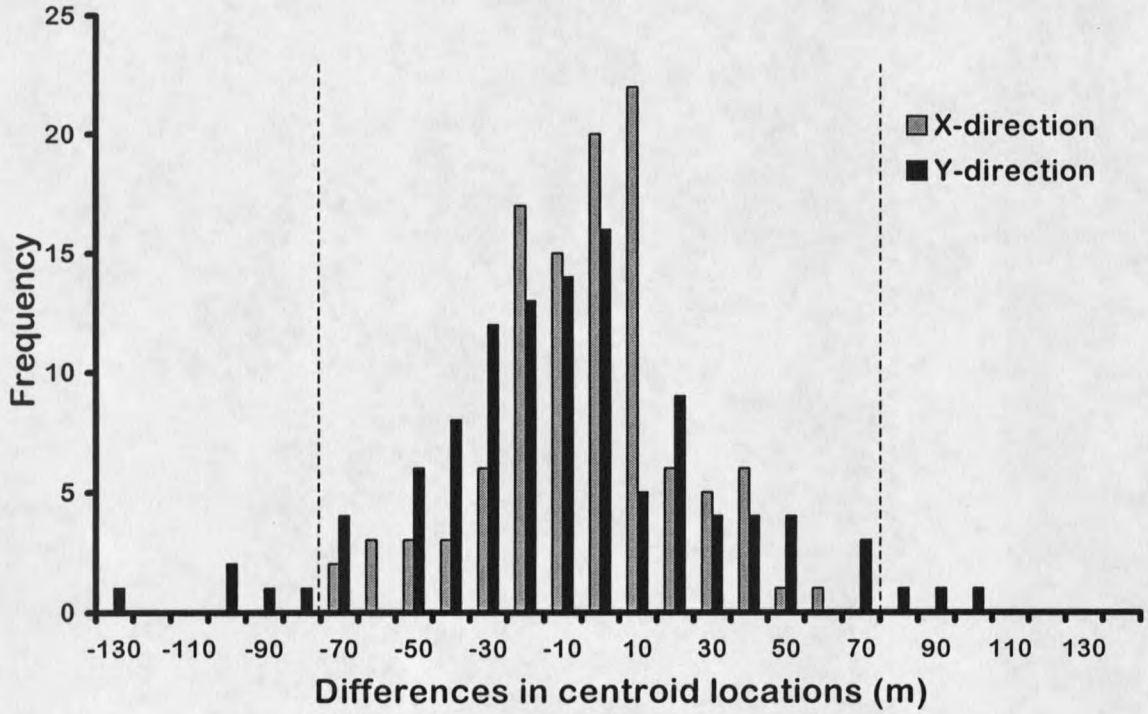


Figure 3. Histogram of Differences in Centroid Locations. Comparison of the spatial concordance of centroids from vegetation polygons mapped by USDA FS (VEG) and the same polygons identified from orthophotographs. Frequency distributions represent differences in UTMs of coordinate pairs (in X and Y directions) from 110 sample polygon centroids. Dashed lines indicate the effective buffer distance necessary to compensate for most of the spatial discrepancy. The distance translates into a cell size of 150m.

Modeling Potential Habitat and Species Richness

Considering the inclusive list of species from pre-development to current, 100% of amphibians modeled either lost potential habitat or had no change in amount of potential habitat (bold-faced font, Table 3; Appendix C). The majority (87.5%) of reptile species lost potential habitat, while one species gained. The majority (72.5%) of avian species lost potential habitat. In the largest avian order, the Passeriformes, 63% of the species lost, 27% gained, and 10% had no change in the amount of potential habitat available. In 5 of the 6 orders of mammals, the majority of species lost potential habitat. Chiroptera was the exception, wherein 70% of the species gained potential habitat. In the two largest mammal groups, Carnivora and Rodentia, 100% of species lost potential habitat. All species that either lost or gained potential habitat equivalent to 20% or more of their pre-development potential habitat are listed in Tables 4 and 5 respectively. The total area lost or gained per species varied widely, but represented a substantial percent change in suitable habitat. All species that lost a large proportion of suitable habitat were associated with either water habitats or grassland/ meadow/shrub habitat (Table 4). All species that gained $\geq$ 20% of suitable habitat were avian, and most were considered urban-associated or urban-adaptable (Table 5). Within the groups of species losing and gaining a large proportion of pre-development potential habitat, 61% and 83% of these species, respectively, were members of the subset most likely to exist in the study area (Tables 4 and 5).

Class	Order	**No Δ**	**Lost**	**Gained**	No Δ	Lost	Gained
		# (%)	**# (%)**	**# (%)**	# (%)	# (%)	# (%)
Amphbia	Anura	**1 (20)**	**4 (80)**	**0 (0)**	1 (20)	4 (80)	0 (0)
Amphbia	Caudata	**0 (0)**	**1 (100)**	**0 (0)**	0 (0)	1 (100)	0 (0)
Reptilia	Squamata	**0 (0)**	**7 (88)**	**1 (13)**	0 (0)	6 (86)	1 (14)
Aves	Anseriformes	**1 (4)**	**26 (93)**	**1 (4)**	0 (0)	20 (100)	0 (0)
Aves	Apodiformes	**1 (17)**	**3 (50)**	**2 (33)**	0 (0)	0 (0)	0 (0)
Aves	Caprimulgiformes	**0 (0)**	**2 (100)**	**0 (0)**	0 (0)	1 (100)	0 (0)
Aves	Charadriiformes	**5 (16)**	**23 (74)**	**3 (10)**	0 (0)	5 (83)	1 (17)
Aves	Ciconiiformes	**0 (0)**	**5 (100)**	**0 (0)**	0 (0)	1 (100)	0 (0)
Aves	Columbiformes	**0 (0)**	**0 (0)**	**2 (100)**	0 (0)	0 (0)	2 (100)
Aves	Coraciiformes	**0 (0)**	**1 (100)**	**0 (0)**	0 (0)	1 (100)	0 (0)
Aves	Cuculiformes	**0 (0)**	**2 (100)**	**0 (0)**	0 (0)	0 (0)	0 (0)
Aves	Falconiformes	**0 (0)**	**16 (94)**	**1 (6)**	0 (0)	13 (93)	1 (7)
Aves	Galliformes	**1 (13)**	**7 (88)**	**0 (0)**	0 (0)	6 (100)	0 (0)
Aves	Gruiformes	**1 (20)**	**3 (60)**	**1 (20)**	1 (50)	1 (50)	0 (0)
Aves	Passeriformes	**12 (10)**	**76 (63)**	**32 (27)**	11 (12)	50 (55)	30 (33)
Aves	Pelecaniformes	**1 (50)**	**1 (50)**	**0 (0)**	0 (0)	1 (100)	0 (0)
Aves	Piciformes	**2 (20)**	**7 (70)**	**1 (10)**	1 (14)	5 (71)	1 (14)
Aves	Podicipediformes	**2 (40)**	**3 (60)**	**0 (0)**	1 (50)	1 (50)	0 (0)
Aves	Strigiformes	**0 (0)**	**11 (79)**	**3 (21)**	0 (0)	6 (86)	1 (14)
Mammalia	Artiodactyla	**2 (29)**	**5 (71)**	**0 (0)**	2 (28.6)	5 (71.4)	0 (0)
Mammalia	Carnivora	**0 (0)**	**20 (100)**	**0 (0)**	0 (0)	19 (100)	0 (0)
Mammalia	Chiroptera	**0 (0)**	**3 (30)**	**7 (70)**	0 (0)	3 (43)	4 (57)
Mammalia	Insectivora	**1 (20)**	**4 (80)**	**0 (0)**	1 (33)	2 (67)	0 (0)
Mammalia	Lagomorpha	**1 (25)**	**3 (75)**	**0 (0)**	1 (25)	3 (75)	0 (0)
Mammalia	Rodentia	**0 (0)**	**24 (100)**	**0 (0)**	0 (0)	21 (100)	0 (0)
Total		**31 (9)**	**247 (74)**	**54 (16)**	19 (8)	175 (74)	41 (17)

Table 3. Summary by Taxonomic Order of Net Change in Potential Habitat. Changes are due to conversion of lands from native vegetation to developed. The number of species that had no change, lost, or gained potential habitat are listed, followed, in parentheses, by the percentage that the number represents for each order. Numbers in bold-faced font represent the summary of the inclusive list of all species that could exist in the study area. Numbers in normal-faced font represent the summary of the subset of species thought most likely to exist in the study area (Appendix C).

COMMON NAME	(Genus species)	Area Lost (ha)	% Δ	Habitat Affinity	STAT
Plains Spadefoot	(Spea bombifrons)	500-600	-32	g/m/s	S
Short-Horned Lizard	(Phrynosoma douglassii)	600-700	-25	g/m/s	S
Sagebrush Lizard	(Sceloporus graciosus)	600-700	-21	g/m/s	g
Canvasback	(Aythya valisineria)	100-200	-22	H_2O	t W
Canada Goose	(Branta canadensis)	600-700	-21	H_2O	B W
Semipalmated Plover	(Charadrius semipalmatus)	100-200	-22	H_2O	t
American Avocet	(Recurvirostra americana)	100-200	-23	H_2O	B
Wilson's Phalarope	(Phalaropus tricolor)	100-200	-25	H_2O	B
Willet	(Catoptrophorus semipalmatus)	500-600	-21	H_2O	B
Marbled Godwit	(Limosa fedoa)	500-600	-21	H_2O	b
Ferruginous Hawk	(Buteo regalis)	600-700	-22	g/m/s	t
Chestnut-Collared Longspur	(Calcarius ornatus)	600-700	-20	g/m/s	b
Lapland Longspur	(Calcarius lapponicus)	600-700	-20	g/m/s	t W
Mccown's Longspur	(Calcarius mccownii)	600-700	-20	g/m/s	b
Vesper Sparrow	(Pooecetes gramineus)	600-700	-20	g/m/s	B
Sprague's Pipit	(Anthus spragueii)	600-700	-20	g/m/s	b
Mink	(Mustela vison)	1-25	-21	H_2O	S A
Richardson's Ground Squirrel	(Spermophilus richardsonii)	600-700	-20	g/m/s	S

Table 4. Species Losing ≥ 20% of Pre-Development Potential Habitat. Losses are due to development. Habitat affinity abbreviations are defined as follows: H_2O represents lakes, ponds, rivers and river habitats; g/m/s represents grassland/meadow/shrub habitats. STAT codes are defined as follows: **S** = specimens from Bozeman latilong (Thompson 1982); **A** = archival data from Gallatin canyon (Picton 1976); **B** = direct evidence of breeding in Bozeman latilong (Bergeron et al. 1992); **b** = indirect evidence of breeding in Bozeman latilong (Bergeron et al. 1992); **t** = observed in Bozeman latilong (Bergeron et al. 1992); **W** = overwinters in Bozeman latilong (Bergeron et al. 1992); **w** = observed during winter in Bozeman latilong (Bergeron et al. 1992); **g** = habitat predicted nearby (Hart et al. 1998). Capital letters indicate membership in the subset of species most likely present.

COMMON NAME	(Genus species)	Area Gained (ha)	% Δ	Habitat Affinity	Urban Response	STAT
Rock Dove	(Columba livia)	500-600	544	altered	associated	t W
Brown-Headed Cowbird	(Molothrus ater)	>800	NA	altered	associated	B
European Starling	(Sturnus vulgaris)	>800	12442	altered	associated	B W
House Sparrow	(Passer domesticus)	1-25	NA	altered	associated	B W
Common Redpoll	(Carduelis flammea)	700-800	111	alpine		t W
Ring-Billed Gull	(Larus delawarensis)	600-700	282	H_2O		t
Harris's Sparrow	(Zonotrichia querula)	700-800	245	coniferous		t W
Violet-Green Swallow	(Tachycineta thalassina)	700-800	748	coniferous		B
Cedar Waxwing	(Bombycilla cedrorum)	100-200	153	coniferous	adaptable	B W
White-Throated Sparrow	(Zonotrichia albicollis)	1-25	NA	coniferous	adaptable	t W
Purple Finch	(Carpodacus purpureus)	700-800	587	coniferous	adaptable	t w
White-Breasted Nuthatch	(Sitta carolinensis)	700-800	444	deciduous		b W
Chimney Swift	(Chaetura pelagica)	700-800	1582	deciduous	adaptable	t
Blue Jay	(Cyanocitta cristata)	700-800	679	deciduous	adaptable	t W
Song Sparrow	(Melospiza melodia)	100-200	33	deciduous	adaptable	b W
Bullock's Oriole	(Icterus bullockii)	600-700	359	deciduous	adaptable	B
Common Grackle	(Quiscalus quiscula)	700-800	377	deciduous	adaptable	B W
Gray Catbird	(Dumetella carolinensis)	100-200	241	deciduous	adaptable	B
Yellow Warbler	(Dendroica petechia)	100-200	241	deciduous	adaptable	B
House Wren	(Troglodytes aedon)	700-800	489	deciduous	adaptable	B
Eastern Screech Owl	(Otus asio)	700-800	400	deciduous	adaptable	b
Killdeer	(Charadrius vociferus)	700-800	236	g/m/s	adaptable	B W
American Goldfinch	(Carduelis tristis)	500-600	411	g/m/s	adaptable	B W
Brewer's Blackbird	(Euphagus cyanocephalus)	700-800	1104	g/m/s	adaptable	B W

Table 5. Species Gaining ≥ 20% of Pre-Development Potential Habitat. Gains are due to development. Habitat affinity abbreviations are defined as follows: altered represents cities, parks, suburbs, fields, orchards, pastures; alpine represents high elevation barren lands; H_2O represents lakes, ponds, rivers and river habitats; g/m/s represents grassland/ meadow/shrub habitats; coniferous represents conifer forest; deciduous represents deciduous forests and thickets. Urban Response describes how the species relates to conversion of native vegetation to an 'altered' habitat. STAT codes are defined as follows: **B** = direct evidence of breeding in Bozeman latilong; **b** = indirect evidence of breeding in Bozeman latilong; **t** = observed in Bozeman latilong; **W** = overwinters in Bozeman latilong; **w** = observed during winter in Bozeman latilong (Bergeron et al. 1992). Capital letters indicate membership in the subset of species most likely present.

Maps of overall species richness using the inclusive list of species and the subset of species most likely to exist in the study area showed similar patterns of relative species richness (Figure 4). Maps of inclusive, overall species richness for the study area under current (Figure 4a) and pre-development vegetation scenarios (Figure 5), indicated that areas of high species richness tend to occur along watercourses and at lower elevations. In the inclusive, current richness map, cells with ≥ 90 species represented the top 17% of richness values. Nearly all of these cells (99%) occurred below 2800m of elevation ($\hat{\mu} =$ 2044m) and within 570m of a stream ($\hat{\eta} = 210$m), whereas the same percentage of all cells, regardless of richness value, occurred below 3100m of elevation ($\hat{\mu} = 2404$m) and within 1320m of a stream ($\hat{\eta} = 390$m) (Figure 6). Nearly half (45%) of these more productive areas occurred in private ownership, though only 24% of the study area was of that ownership class. Most (59%) of the cells containing ≥ 90 species occurred in Douglas-fir or mixed Douglas-fir/ lodgepole pine stands, with an additional 33% occurring in grasslands, meadows, and shrub habitats.

The pattern of inclusive, overall species richness (Figure 4a) corresponded with gross patterns for individual classes of species based on the inclusive list (Figure 7). Likewise, the patterns of overall species richness and class-level species richness also corresponded for the subset of species most likely to exist in the study area (Figures 4b and 8, respectively). In Figures 7 and 8, the 3 richest categories in each map represent richness values above the mean for that vertebrate class. The pattern for Amphibia showed the strongest association between high richness and proximity to stream. The pattern for Reptilia also showed this association, as well as the influence of elevation, with highest richness at lower elevations. High richness for Aves and Mammalia was

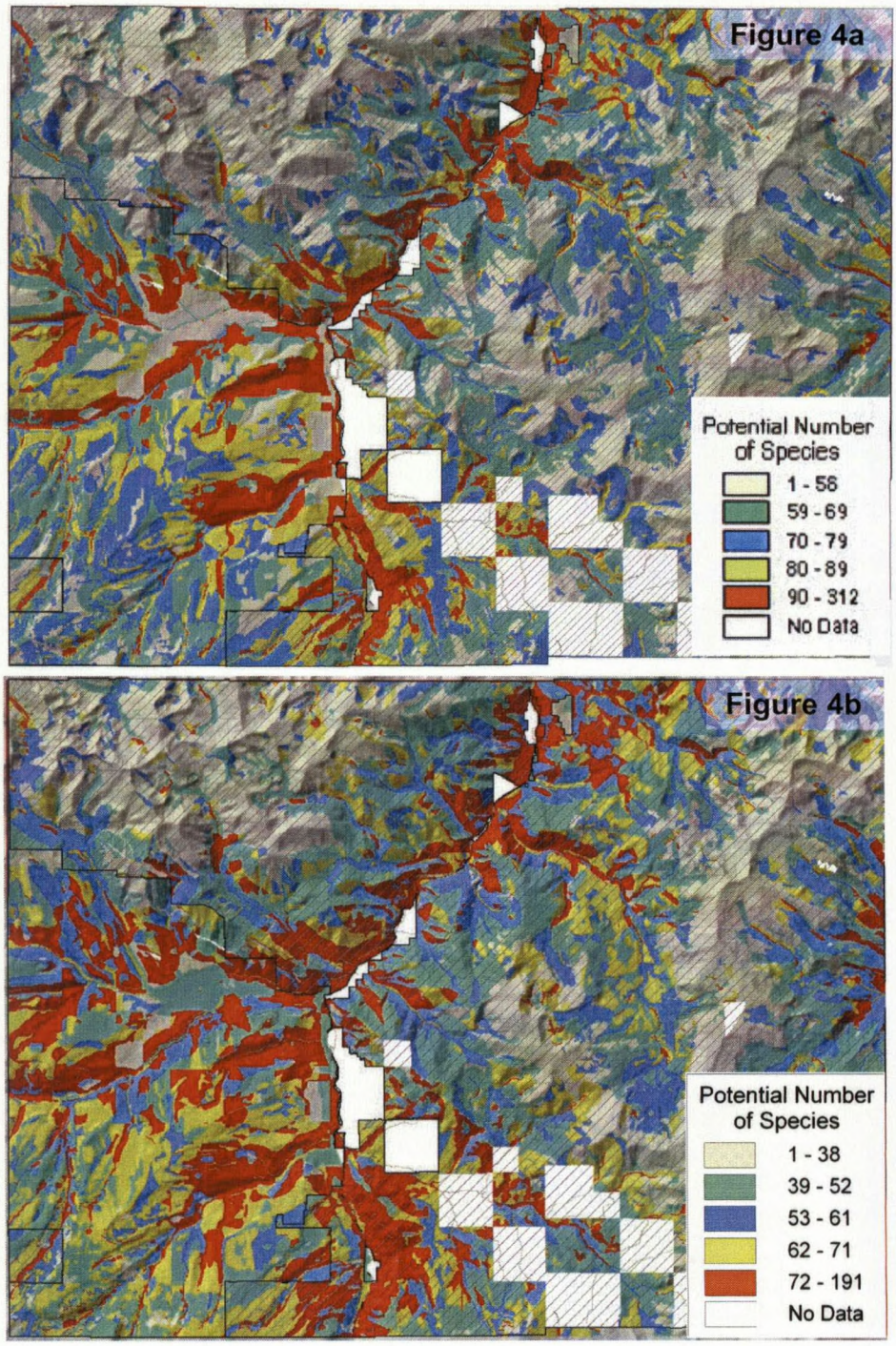


Figure 4. Predicted Overall Species Richness – Inclusive and Most Likely Subset. Maps of overall species richness for the inclusive list (Figure 4a) and the most likely subset (Figure 4b) were created by summing potential habitat maps of 342 and 235 species, respectively. Data for modeling included the 30m VEGGAP. Top 3 categories on each map represent above-mean richness values. Hashed areas represent public lands.

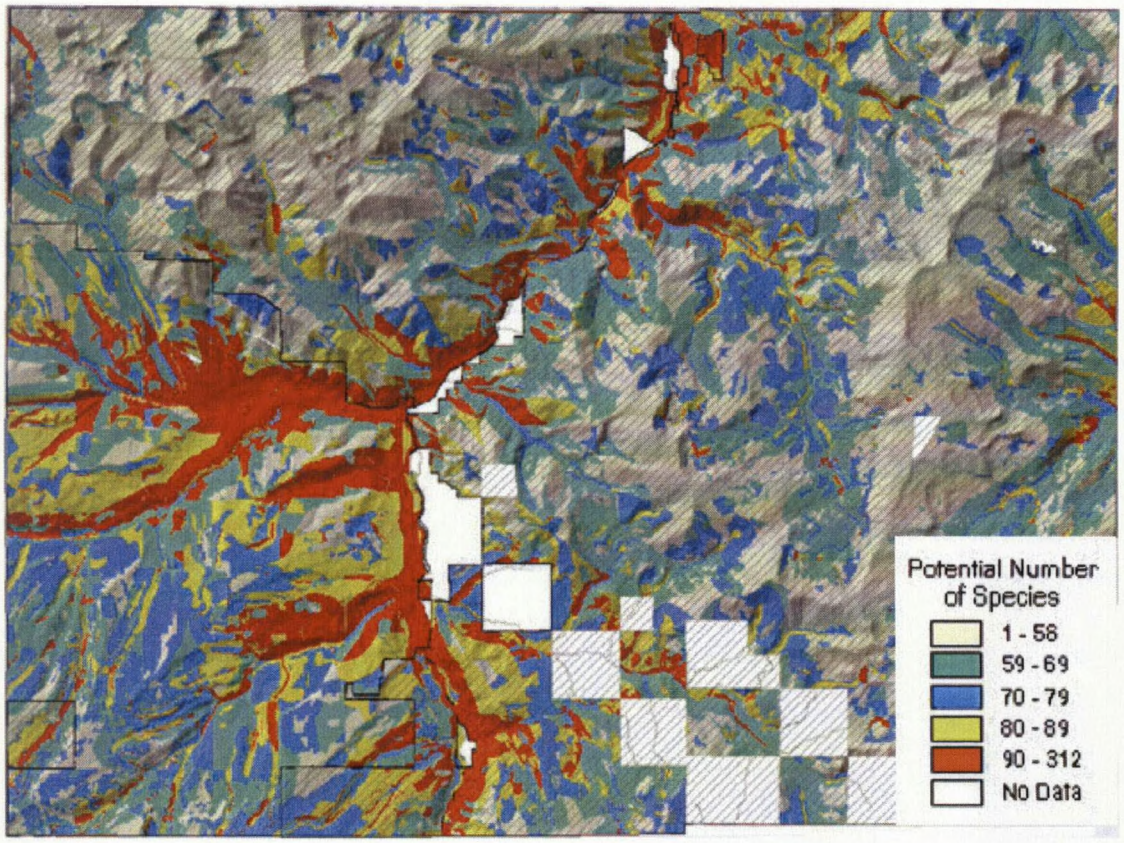


Figure 5. Predicted Overall Species Richness – Pre-Development. Map of pre-development potential species richness was created by summing potential habitat maps of the inclusive list of 342 species modeled by the MT GAP rules. Data for modeling included the 30m VEGGAP62. Top 3 categories represent above-mean richness.

generally more spatially dispersed, but the association between streams and richness was evident. Additionally, the dearth of species at the highest elevations suggested elevation also had an influence on species richness for these two classes. Class level maps of species of special concern also agreed with the general pattern described above (Figures 9 and 10). The one amphibian species was closely associated with streams, while richness of the avian and mammalian species was more dispersed, but reduced at the highest elevations. The map of total species of special concern (Figure 9) showed a relative richness pattern very similar to the overall species richness in Figure 4a.

Figure 6a

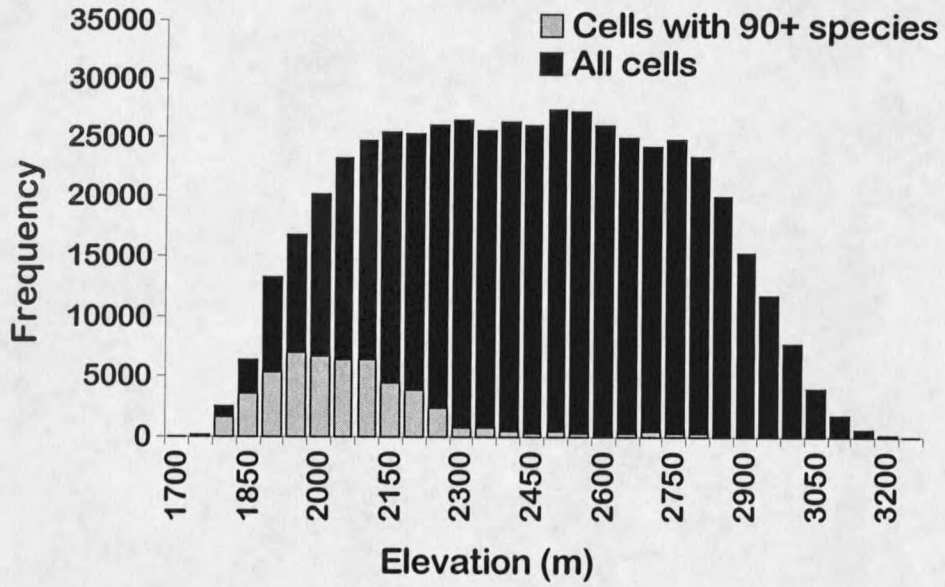


Figure 6b

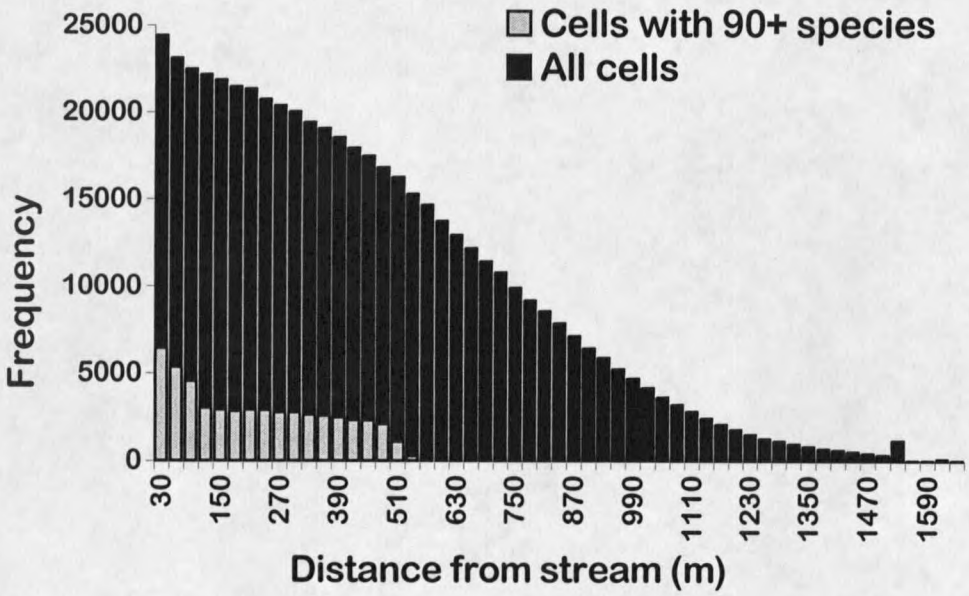


Figure 6. Histograms of Elevation and Distance to Stream Values Associated with High Species Richness. Values for elevation (Figure 6a) and distance to stream (Figure 6b) of cells comprising the top 17% overall species richness values versus all cells in the study area (for inclusive species list). Cells with 90 or more species occur relatively closer to streams and at lower elevations than do all cells regardless of richness value.

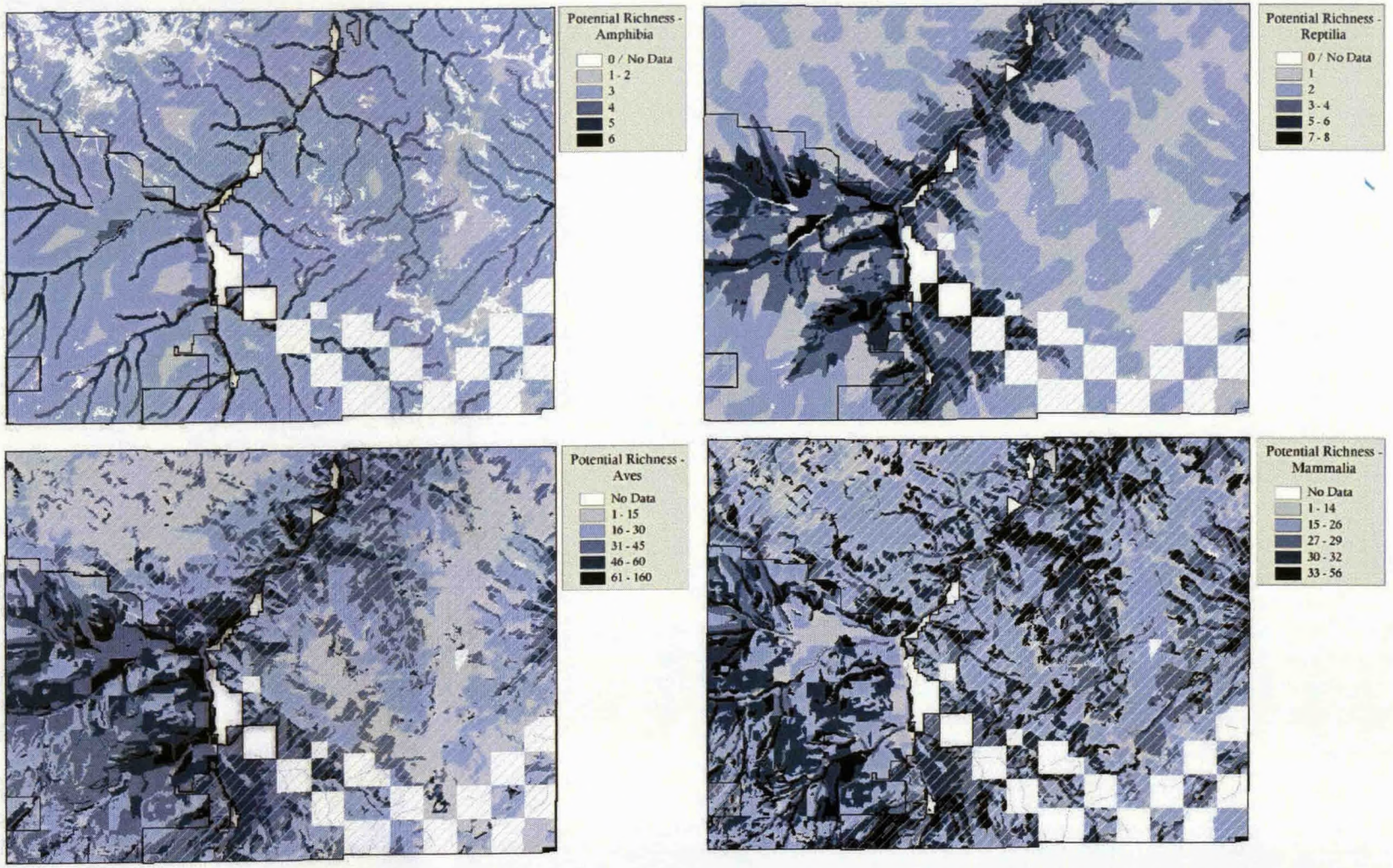


Figure 7. Potential Richness Maps by Taxonomic Class – Inclusive List. Patterns of high richness tend to follow watercourses and occur at lower elevations. The 3 richest categories in each map represent above average richness for that class. Hashed pattern designates public land.

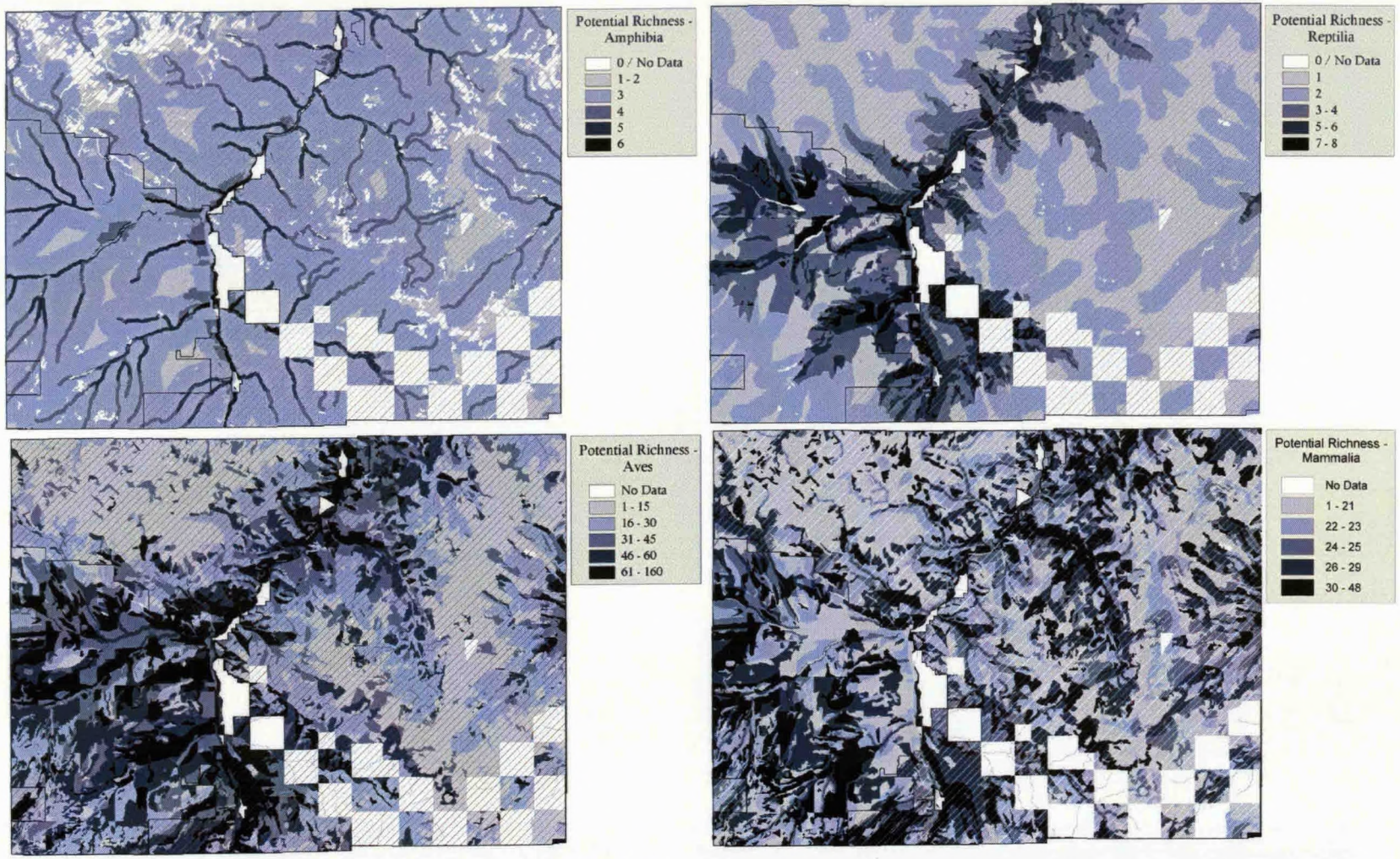


Figure 8. Potential Richness Maps by Taxonomic Class – Most Likely Subset. Relative patterns of richness are similar to those from the inclusive list. Patterns of high richness tend to follow watercourses and occur at lower elevations. The 3 richest categories in each map represent above average richness for that class. Hashed pattern designates public land.

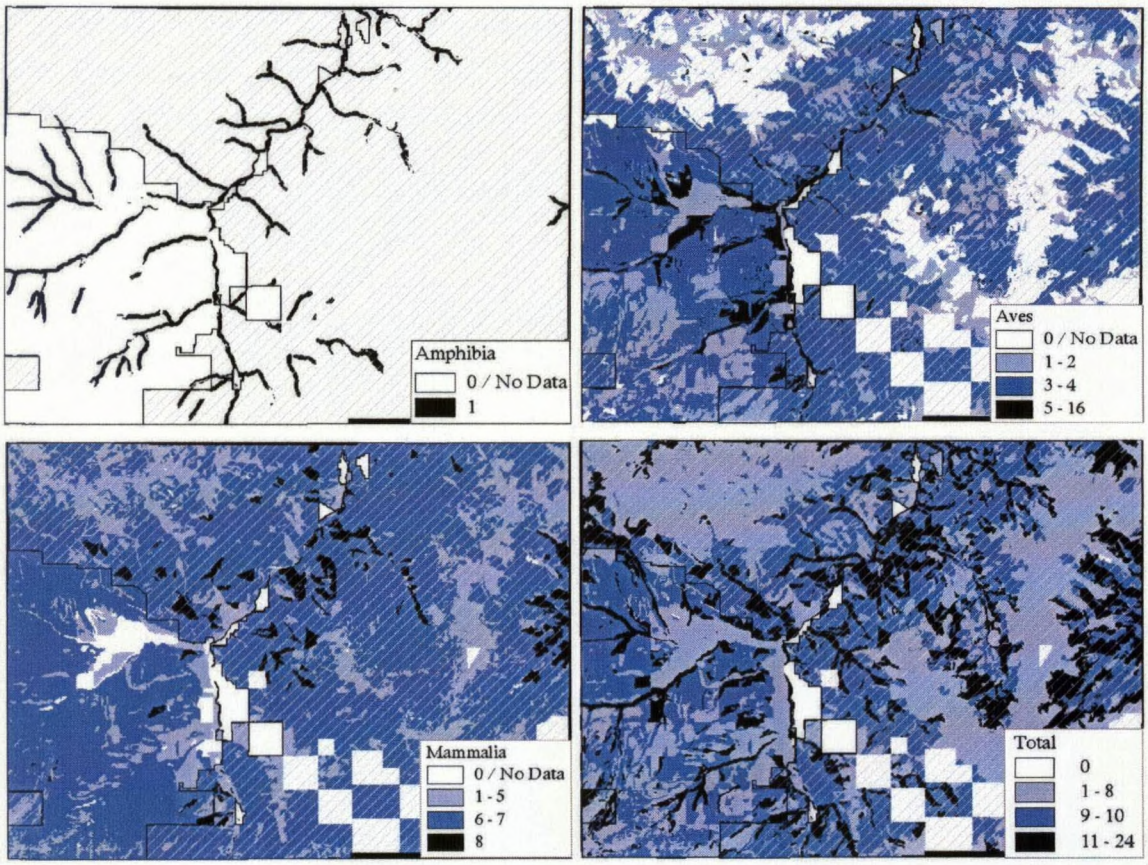


Figure 9. Potential Richness Maps for Species of Special Concern – Inclusive. Patterns of high richness for individual taxonomic classes are not unlike the pattern of overall species richness. (Note there are no reptilian species of special concern, and the lower right map represents all species of special concern.) Hashed pattern designates public land.

The effect on overall species richness of converting land from native vegetation to urban was summarized in the map differencing the two inclusive richness maps, pre-development minus current (Figure 11). Most (72.2%) of the study area had no net change in potential species richness. The area most impacted by development thus far was the drainage of the West Fork of the Gallatin River. All pixels in this area under the inclusive, pre-development scenario had potential species richness in the highest category, i.e., $\geq$ 90 species, yet under the inclusive, current scenario, potential richness on

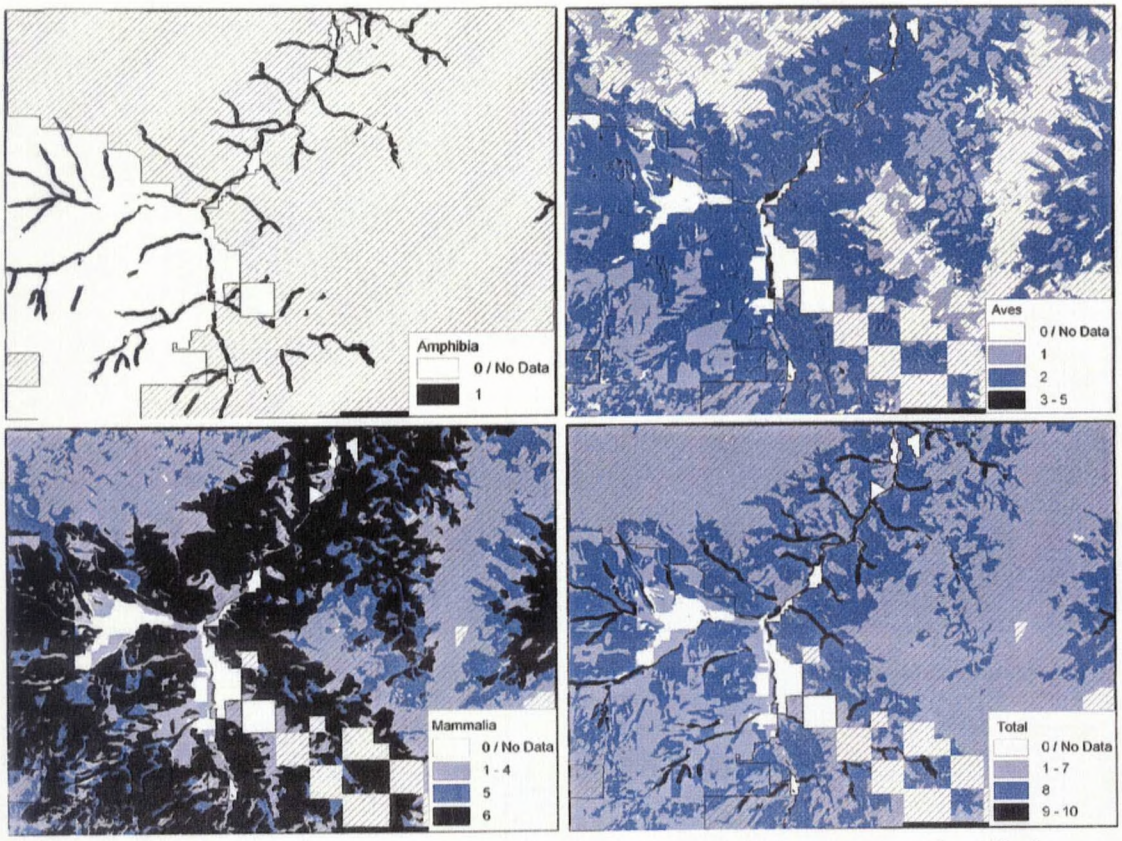


Figure 10. Potential Richness Maps for Species of Special Concern – Most Likely Subset. Patterns of high richness for individual taxonomic classes are not unlike the pattern of overall species richness. (Note there are no reptilian species of special concern, and the lower right map represents all species of special concern.) Hashed pattern designates public land.

these same sites dropped to the lowest category, i.e., < 59 species (Figures 5 and 4a, respectively). The change represents a potential net loss of 35 – 206 species. In addition to the West Fork drainage, some pockets along the Gallatin River have experienced a net loss of potential habitat for 1 – 70 species. The total area experiencing a net loss of potential richness accounted for 1.5% of the study area, while a larger proportion (26.3%) experienced a net gain of 1 to 2 species. In these areas, development increased potential habitat for the European starling (*Sturnus vulgaris*) and the Brown-headed cowbird (*Molothrus ater*), both urban-associated species.

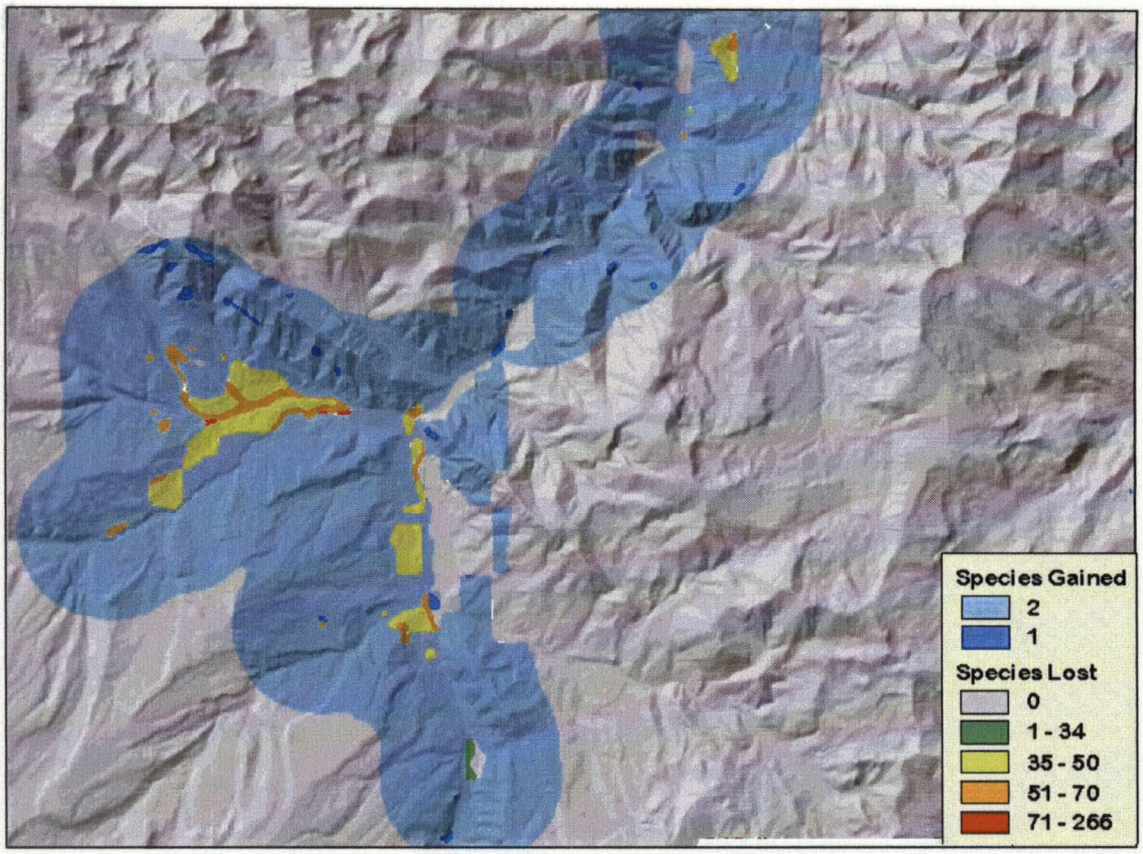


Figure 11. Difference in Richness from Pre-Development to Current. Map is the result of the difference in species richness from the inclusive list of species modeled with "pre-development" vegetation data and current vegetation data (Figures 5 and 4a, respectively). Numbers of species gained or lost are due to conversion of native vegetation to "urban".

Rates of Urbanization and Impact on Vegetation

Log-linear regression on the number of buildings present at five time points estimated an annual growth rate of 4.7% (se=0.004; p=0.001 for H_0: slope = 0) over the entire 36-year interval, which equates to the addition of 22 buildings per year on average (Figure 12). From 1962 to 1971, the number of buildings increased from 192 to 243. From the approximate establishment of the Big Sky Ski and Summer Resort in 1971 to 1981, the number of buildings increased to 507. By 1985, there were 858 buildings, and

a final count in 1998 recorded 963 buildings in the study area (Figure 13). Most of the buildings (67%) were located in grasslands, meadows, or shrublands, 21% in coniferous forest (84% of these in Douglas-fir), 3% in riparian zones, and 9% other. The buildings were located between 1,750–2260m elevation ($\hat{\mu} = 1900$m), within 2–1,456m of a stream ($\hat{\mu} = 251$m), and within 0–230m of a road ($\hat{\mu} = 31$m).

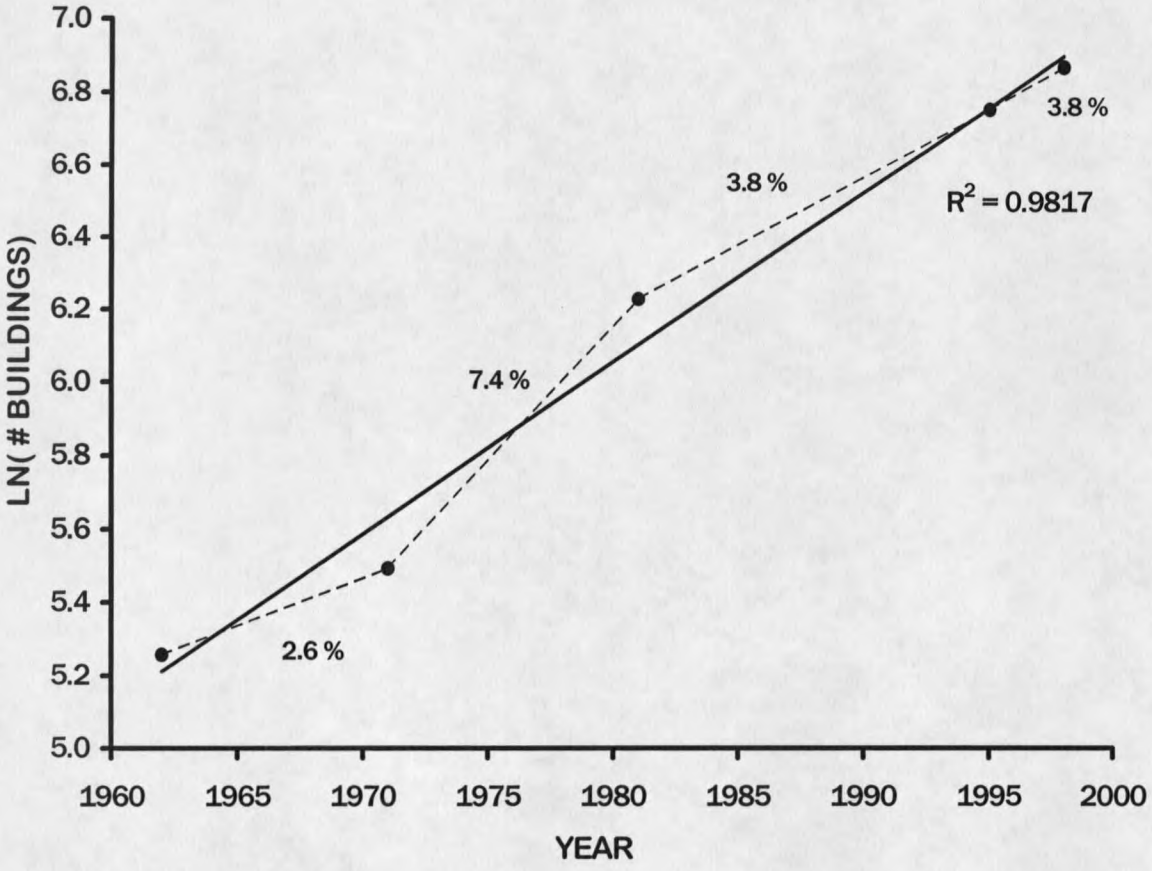


Figure 12. Annual Rate of Growth – 1962 to 1998. Regression of the natural log of the number of buildings present in the Gallatin Canyon/Big Sky planning district over time. Five data points (1962, 1971, 1981, 1995 and 1998) were obtained via digitizing from orthophotographs and subsequent aerial photo interpretation. The overall annual growth rate is 4.7%, with inter-data point growth rates shown beside the dashed line.

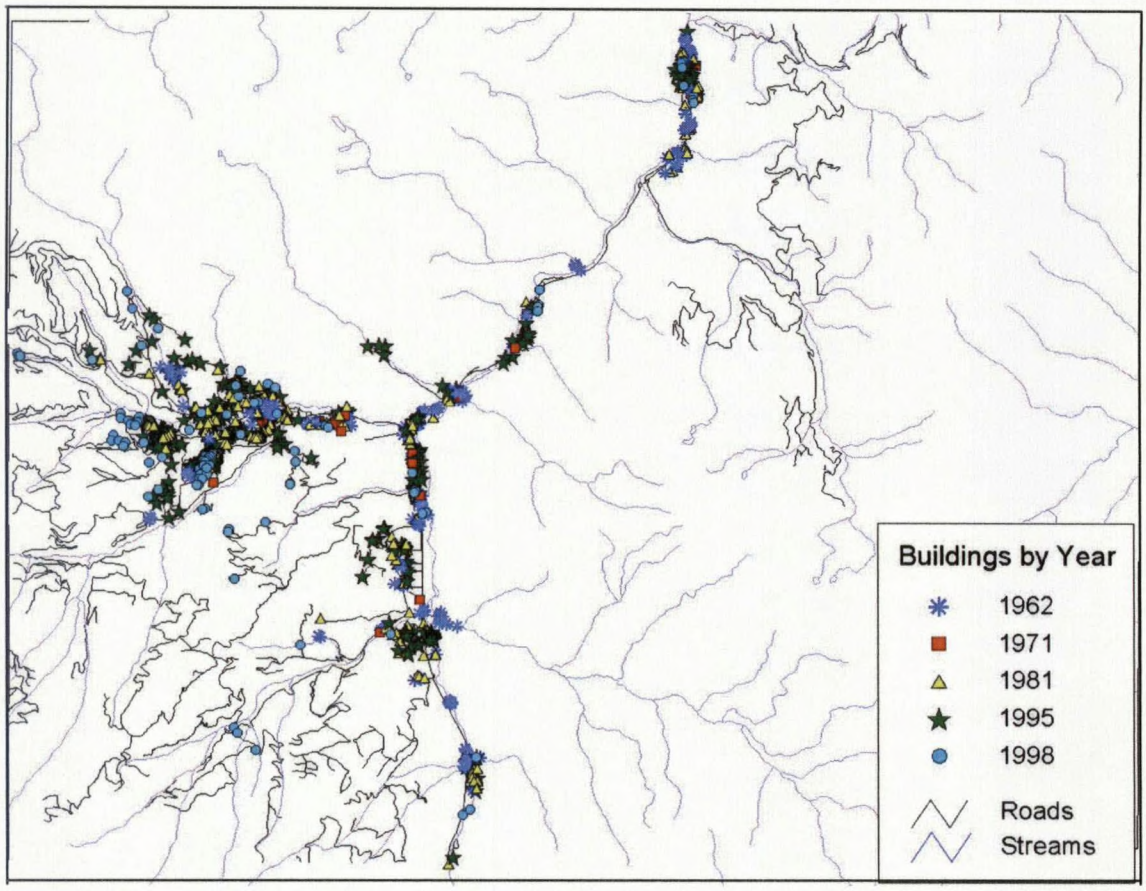


Figure 13. Building Locations through Time. Marker symbols represent the aerial photo year that the building was first present.

Impact of development on native vegetation was not distributed evenly among the available vegetation types (Table 6). Of the 806 ha of land classified as urban cover type, the low/moderate cover grasslands (native cover) accounted for most of this area, followed by Douglas-fir, montane parklands and subalpine meadows, mixed xeric shrub, conifer riparian, and Douglas-fir/lodgepole pine mix. The cover type water gained approximately 4 ha due to the creation of ponds. Results from exact binomial tests (Table 7) indicated that low/moderate cover grasslands, montane parklands and subalpine meadows, mixed xeric shrub, and riparian were all used more than expected based upon

their availability ($p < 0.05$). Douglas-fir/lodgepole pine mix was used in proportion to its availability ($p > 0.05$), while the rest of the impacted cover types were used less than expected ($p < 0.05$).

Vegetation Type (GAP)	1962 Area (ha)	1998 Area (ha)	Converted (ha)	Converted %
Low/Moderate Cover Grasslands	2252.5	1601.6	651.0	29
Moderate/High Cover Grasslands	71.2	70.4	0.8	1
Montane Parklands & Subalpine Meadows	77.2	44.7	32.5	42
Mixed Xeric Shrubs	16.1	0.0	16.1	100
Mixed Broadleaf Forest	24.0	24.0	0.0	0
Lodgepole Pine	3606.2	3603.8	2.4	0
Doglas-fir	3830.6	3747.5	83.1	2
Douglas-fir/Lodgepole Pine	93.7	85.3	8.4	9
Mixed Whitebark Pine Forest	143.9	143.9	0.0	0
Mixed Sub-alpine Forest	1207.2	1207.2	0.0	0
Water	99.0	103.0	-4.0	NA
Conifer Riparian	15.5	0.0	15.5	100
Graminoid & Forb Riparian	0.8	0.8	0.0	0
Shrub Riparian	0.6	0.0	0.6	100
Rock	154.1	154.1	0.0	0
Alpine Meadows	30.6	30.6	0.0	0
Total	11623.2	10816.8	806.4	6.9

Table 6. Area of Native Vegetation Types Impacted by Development. Data from 1962 result from the re-classification of polygons labeled as urban cover type in the VEGGAP data layer to their native cover types via aerial photo interpretation. Data reflect only those lands in private ownership.

Cover Type	Available		Converted		Binomial	Selection
	# cells	% cells	# cells	% cells	*p*-values	
Low - moderate cover grasslands	25028	0.194	7233	0.807	< 0.0001	Preferred
Moderate - high cover grasslands	791	0.006	9	0.001	< 0.0001	Avoided
Montane Parklands & sub-alpine meadows	858	0.007	361	0.040	< 0.0001	Preferred
Mixed xeric shrub	179	0.001	179	0.020	< 0.0001	Preferred
Mixed broadleaf forest	267	0.002	0	0.000	< 0.0001	Avoided
Lodgepole pine	40069	0.310	27	0.003	< 0.0001	Avoided
Douglas-fir	42562	0.330	923	0.103	< 0.0001	Avoided
Douglas-fir/Lodgepole pine	1041	0.008	93	0.010	0.7505	As expected
Mixed Whitebark pine forest	1599	0.012	0	0.000	< 0.0001	Avoided
Mixed Sub-alpine fir	13413	0.104	0	0.000	< 0.0001	Avoided
Riparian	188	0.001	179	0.020	< 0.0001	Preferred
Rock	1712	0.013	0	0.000	< 0.0001	Avoided
Alpine meadows	340	0.003	0	0.000	< 0.0001	Avoided

Table 7. Results from Exact Binomial Tests – Use vs. Availability. Exact binomial tests were conducted for all cover types present in private ownership. Available data represent private lands only. Columns "% cells" represent the proportion of total cells either available or converted for each cover type. *P*-values shown in the Binomial column are interpreted under Selection. Cover types Broadleaf Riparian, Graminoid and Forb Riparian, and Shrub Riparian were combined into Riparian due to small cell counts for the available class.

Potential Future Urbanization and Conflict Avoidance

Significant predictors of development ($p < 0.1$) were distance to roads, distance to streams, elevation, slope, aspect, percent conifer, percent riparian, percent rock, percent grass/shrub/meadow, grazing status, vegetation diversity, and neighborhood density. Most (72%) of the Mahalanobis values for the 100 cells reserved for validation data were less than or equal to 15, the threshold value corresponding to the first 20% quantile of all data, thereby indicating high similarity to developed areas (Figure 14). Mapping the Mahalanobis distances resulting from the predictive model identified sites suitable for development (Figure 15). The areas most suitable for development were along the West Fork of the Gallatin River, the South and North Forks of the West Fork, the Gallatin River between the West Fork and Beaver Creek, and, Crail, Michener, and Beaver Creeks.

Displayed in the 20% quantiles, the Mahalanobis values indicated that areas more suitable for development (values ≤ 15) occurred relatively closer to roads, closer to streams, and at lower elevations than all cells in private ownership. Elevation values for nearly all of the top 20% of cells (99%) occurred below the median value for all cells in private ownership ($\hat{\eta}_{all} = 2165$m, $\hat{\eta}_{\leq 15} = 1978$m; Figure 16a). Distances to the nearest road for nearly all of the top 20% of cells (98%) occurred below the median value for all cells in private ownership ($\hat{\eta}_{all} = 212$m, $\hat{\eta}_{\leq 15} = 86$m), and 62% of the distance to stream values were lower than the median distance value for all cells in private ownership ($\hat{\eta}_{all} = 360$m, $\hat{\eta}_{\leq 15} = 278$m – Figure 16b).

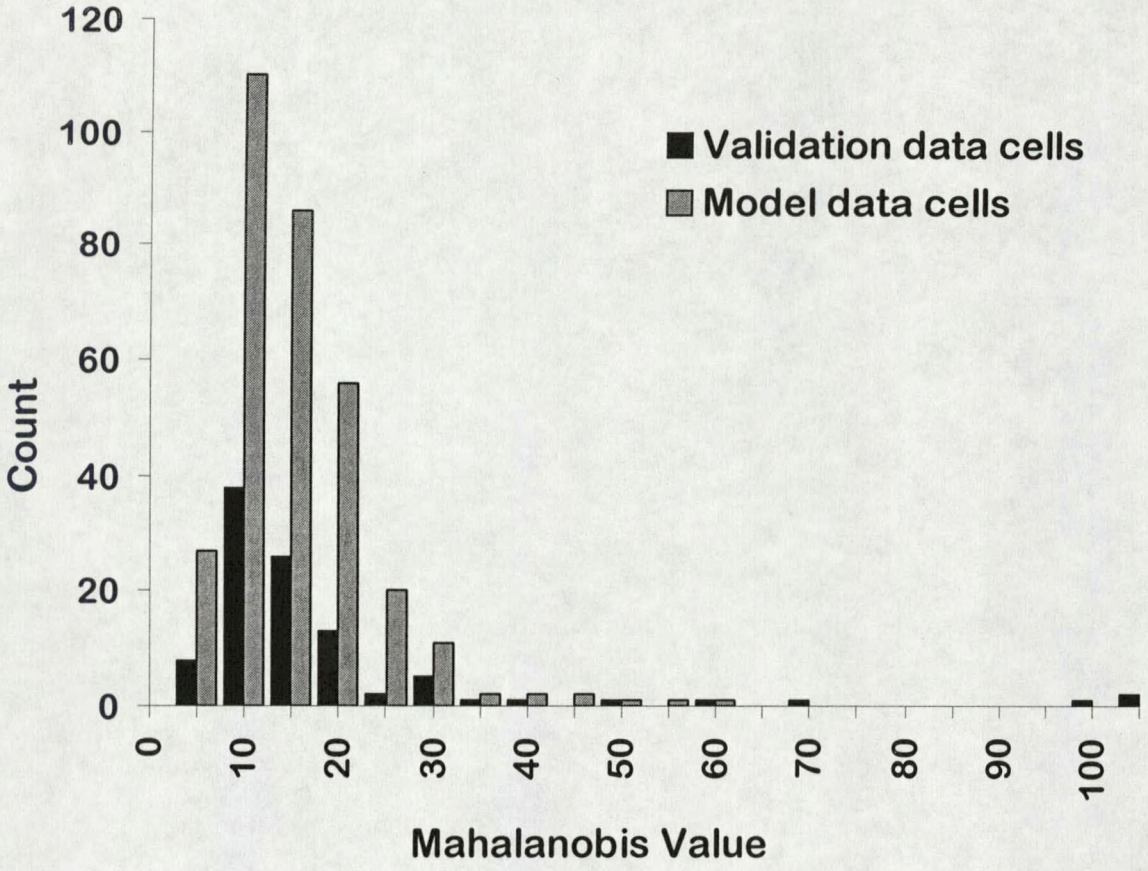


Figure 14. Frequency Distributions of Mahalanobis Values. Data shown are from the 100 cells reserved from model creation for the validation data set and for the data used to create the model. Of the validation data, 72% had Mahalanobis values ≤ 15 (corresponding to the threshold value for the top 20% of all Mahalanobis values for private lands), while 69% of the model data had values in that range. Median Mahalanobis values for the two groups were 10.5 and 11.2, respectively.

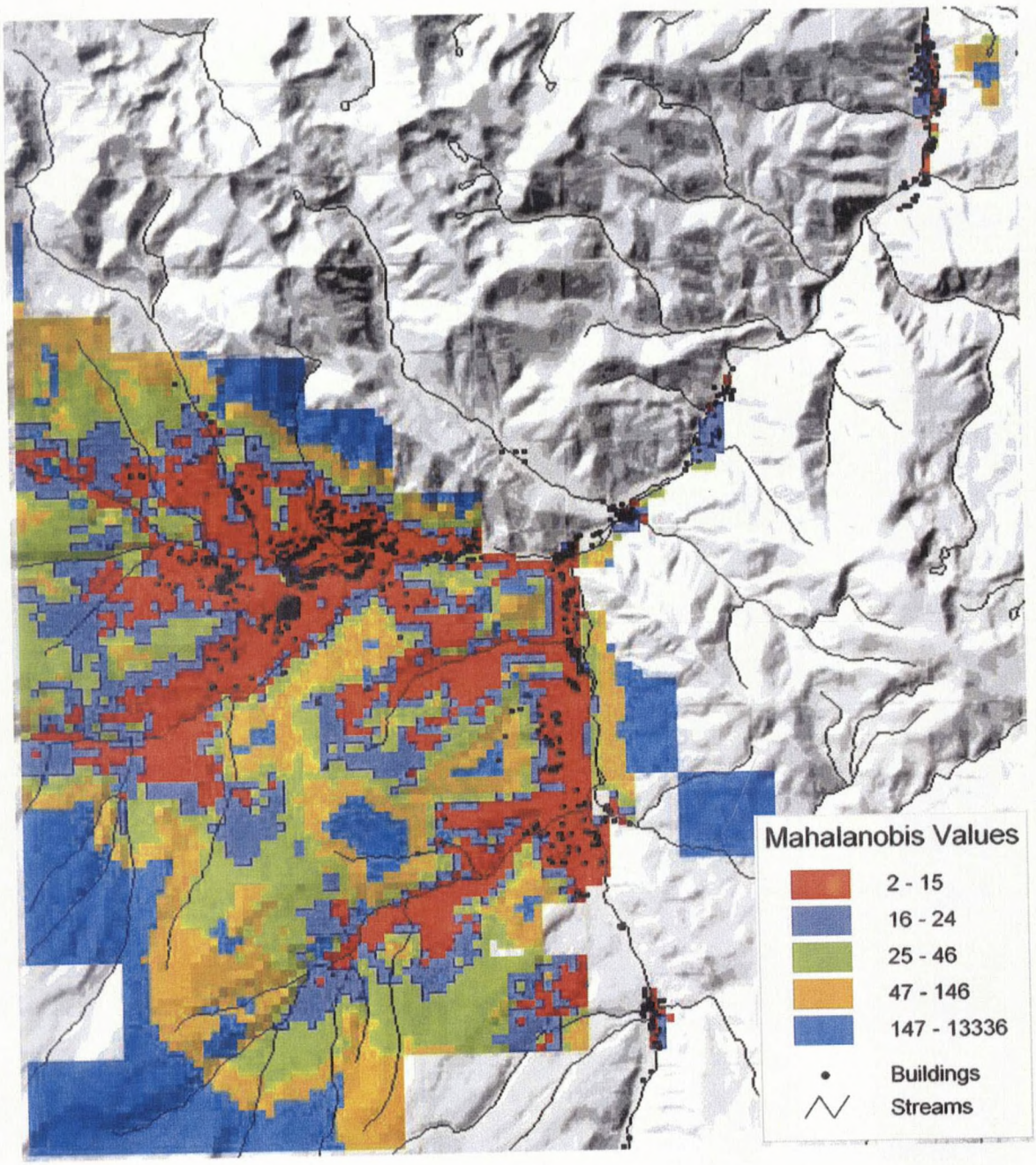


Figure 15. Mapped Mahalanobis Values. Mahalanobis distances calculated for private lands only and displayed in 5 quantiles, each representing 20% of the data. Lower Mahalanobis values (red) indicated conditions most similar to the multivariate mean vector calculated from 321 cells containing buildings (building locations shown as black dots).

Figure 16a

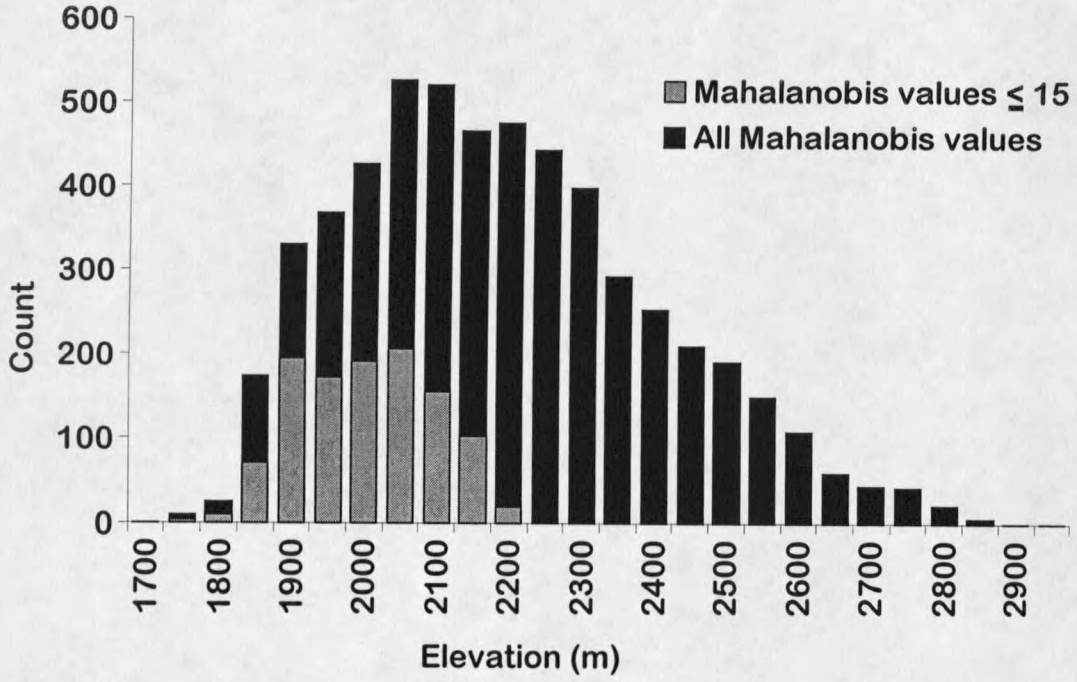


Figure 16b

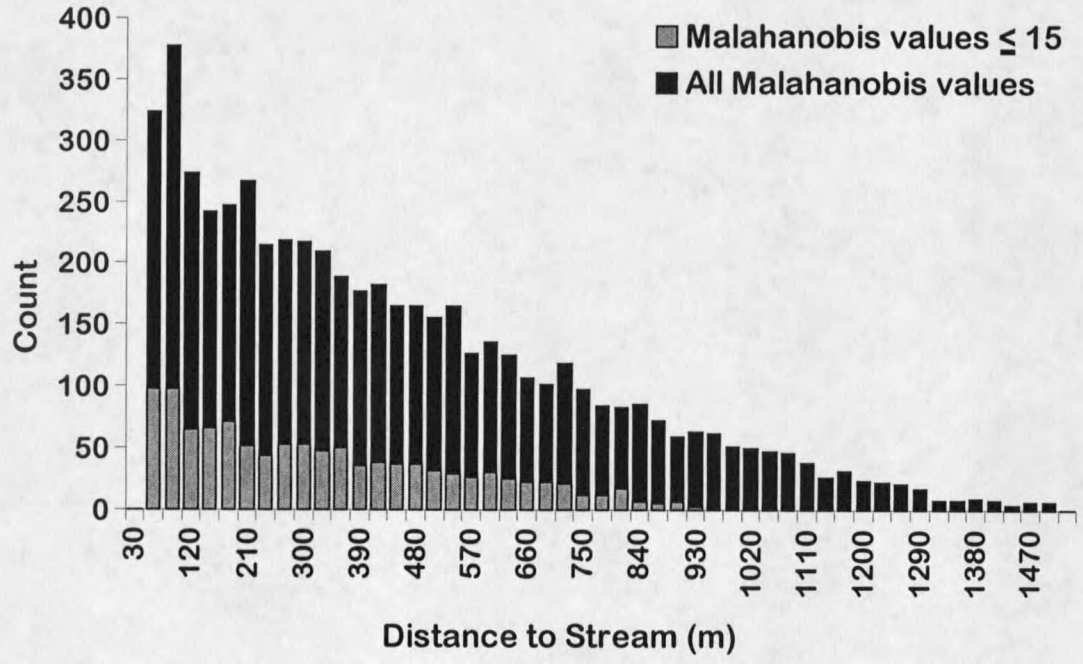


Figure 16. Histograms of Elevation and Distance to Stream Values Associated with High Suitability for Development. Frequency distributions of values for elevation (Figure 16a) and distance to stream (Figure 16b) of cells comprising the top 20% of Mahalanobis values versus the same frequency distributions for all cells in private ownership (excluding no data cells).

For both the inclusive list of species and the subset of species most likely to exist in the study area, areas of potential conflict between suitable development sites and overall species richness were located primarily along the South Fork of the West Fork, Michener Creek, and Beaver Creek, with additional conflict areas along the North Fork of the West Fork and Crail Creek (Figures 17 and 18). This general pattern held for the class-level analyses (Figures 19 and 20) and overall species of special concern (Figures 21 and 22). High amphibian richness conflicted with suitable development sites primarily along the narrow riparian corridors the South Fork of the West Fork, Michener Creek, Beaver Creek, and the Gallatin River. The conflict patterns for reptilian and avian richness were very similar to each other as well as to the conflict pattern for overall richness, with the main difference being the inclusion of the West Fork of the Gallatin River as an area of level 3 conflict in the class-level assessments. Conflict with high mammalian richness was localized to the upper reaches of the West Fork of the Gallatin River and the South Fork of the West Fork and the lengths of Michener and Beaver Creeks. The conflict pattern for the species of special concern was again very similar to those for reptiles, birds, and overall richness.

Conflict Map – Overall Species Richness (Inclusive)

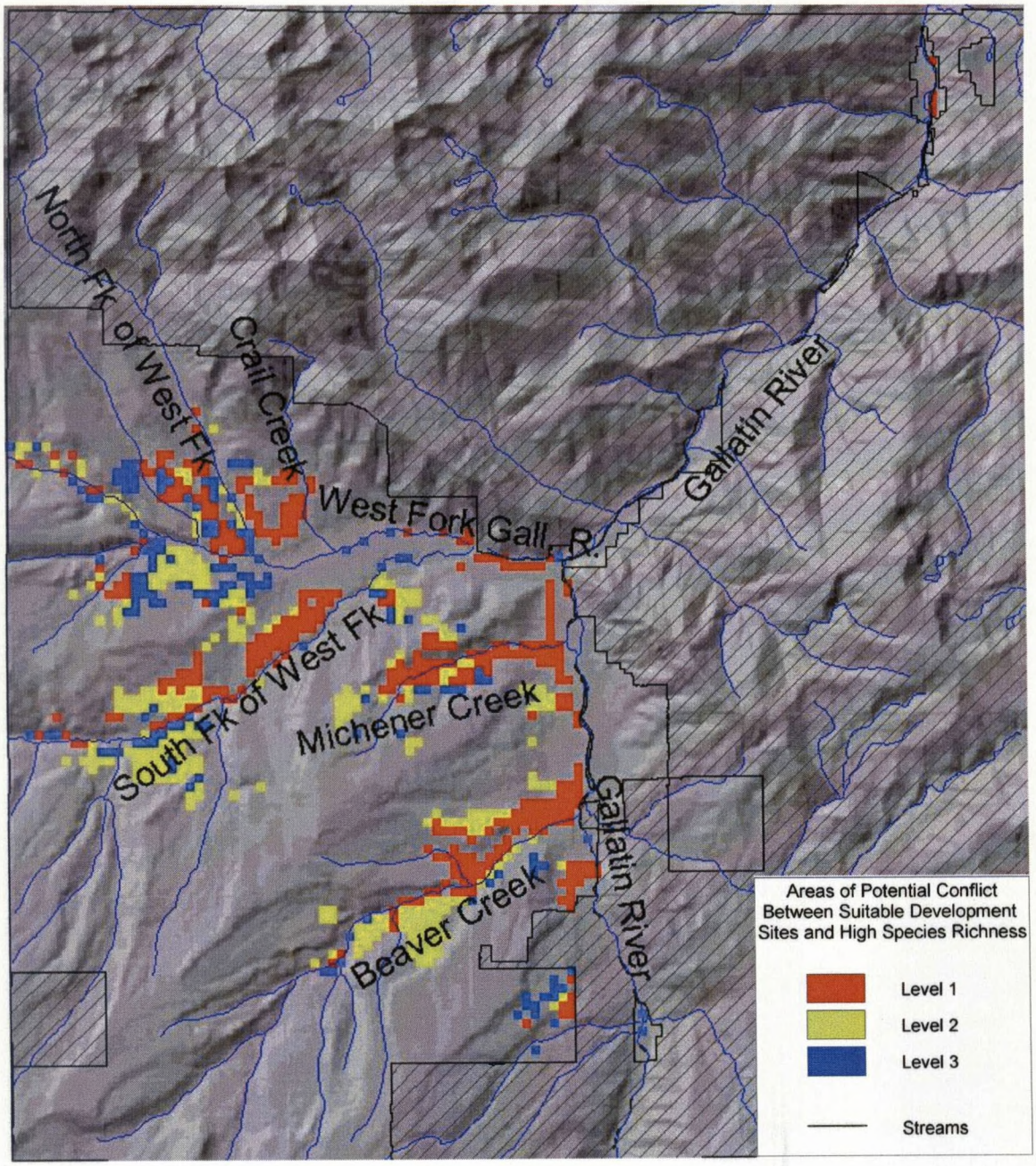


Figure 17. Areas of Potential Conflict – Overall Species Richness (Inclusive). Areas of potential conflict between suitable development sites and high overall species richness. Level 1 indicates areas with potential richness of 90+ species; Level 2, 75-89 species; Level 3, 58-74 species. All levels have a Mahalanobis value of ≤ 15. Hashed areas are public lands.

Conflict Map – Overall Species Richness (Most Likely Subset)

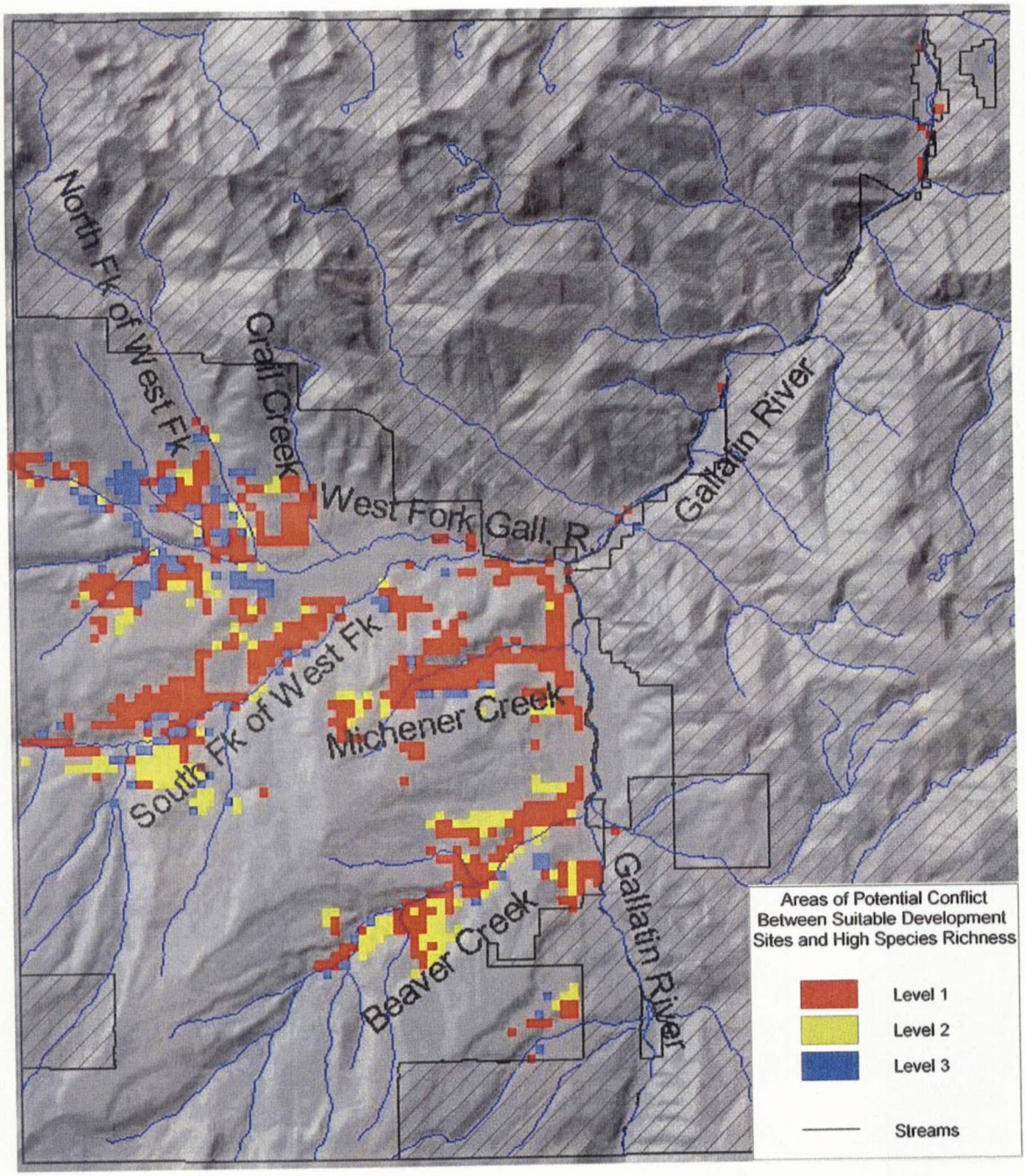


Figure 18. Areas of Potential Conflict – Overall Species Richness (Most Likely Subset). Areas of potential conflict between suitable development sites and high overall species richness. Level 1 indicates areas with potential richness of 72+ species; Level 2, 62-71 species; Level 3, 53-61 species. All levels have a Mahalanobis value of ≤ 15. Hashed areas are public lands.

Conflict Maps – Class-level Species Richness (Inclusive)

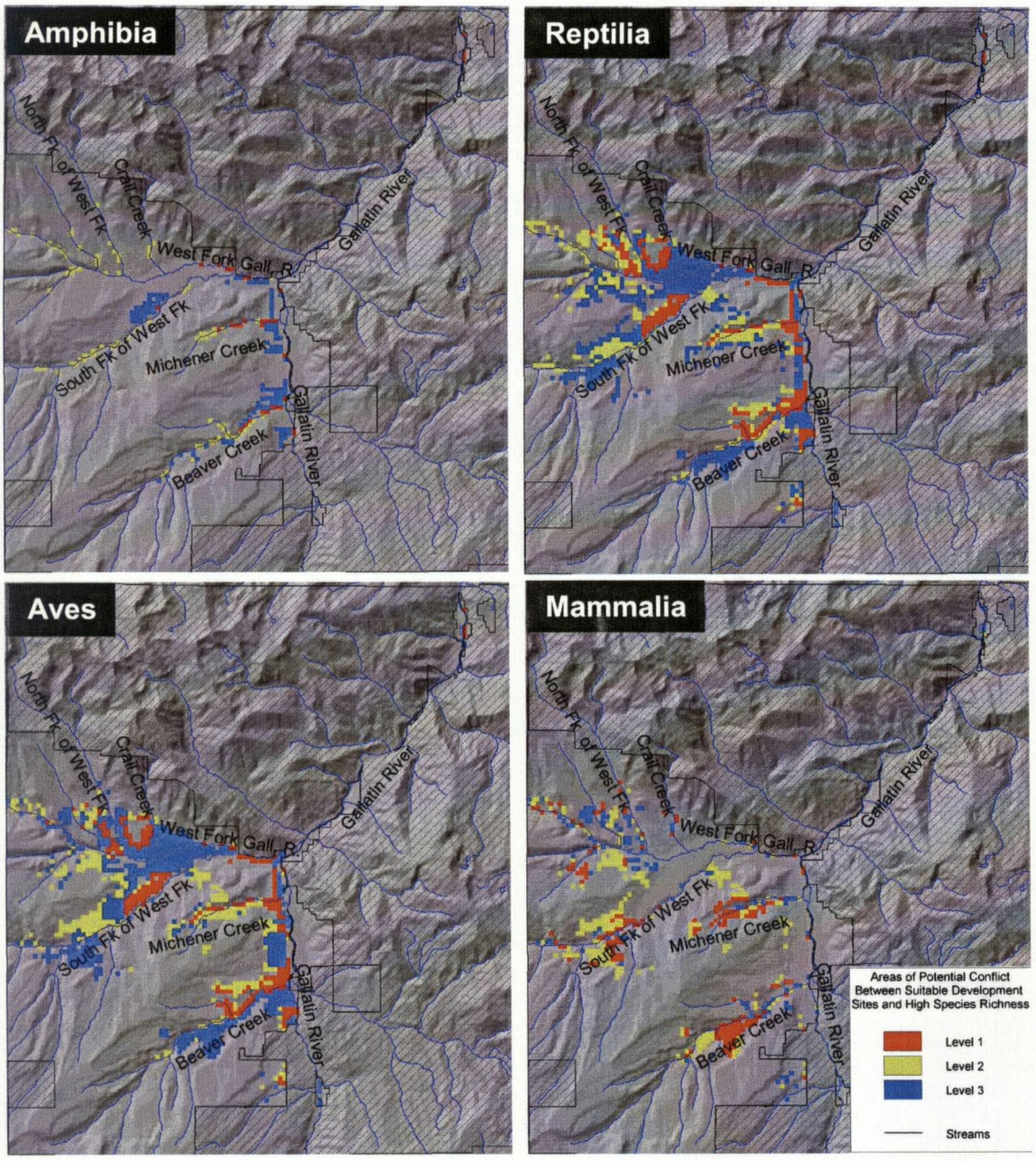


Figure 19. Areas of Potential Conflict – Class-Level Species Richness (Inclusive). Class-level maps of areas of potential conflict between suitable development sites and above average species richness. Conflict areas occur where suitable development sites (Mahalanobis values ≤ 15) coincide with an above average richness value (the 3 richest categories for each class in Figure 7). Level 1 indicates areas in the highest potential richness category; Level 2, the second highest; Level 3, the third highest. Hashed areas are public lands.

Conflict Maps – Class-level Species Richness (Most Likely Subset)

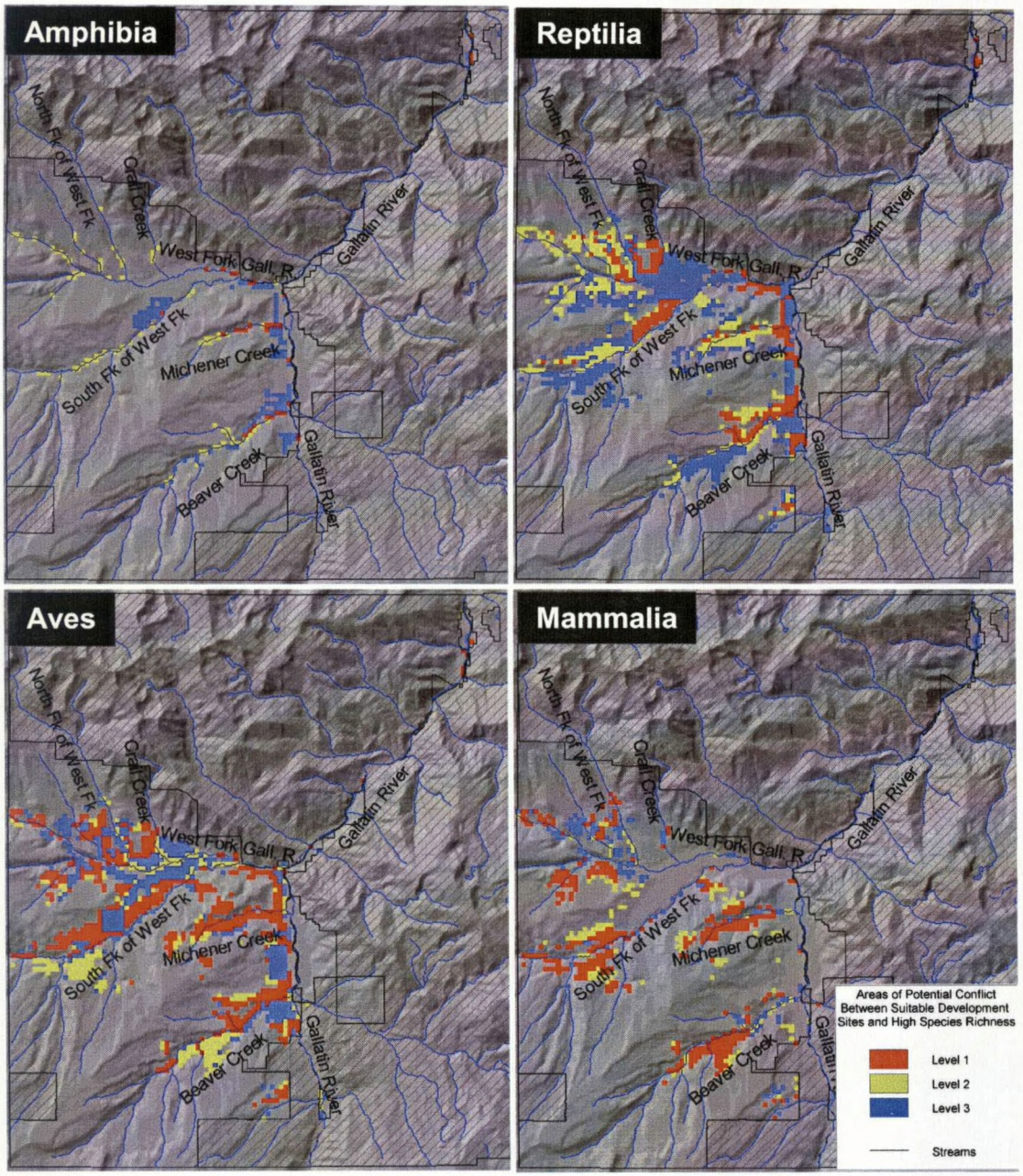


Figure 20. Areas of Potential Conflict – Class-Level Species Richness (Most Likely Subset). Class-level maps of areas of potential conflict between suitable development sites and above average species richness. Conflict areas occur where suitable development sites (Mahalanobis values ≤ 15) coincide with an above average richness value (the 3 richest categories for each class in Figure 8). Level 1 indicates areas in the highest potential richness category; Level 2, the second highest; Level 3, the third highest. Hashed areas are public lands.

Conflict Map – Species of Special Concern (Inclusive)

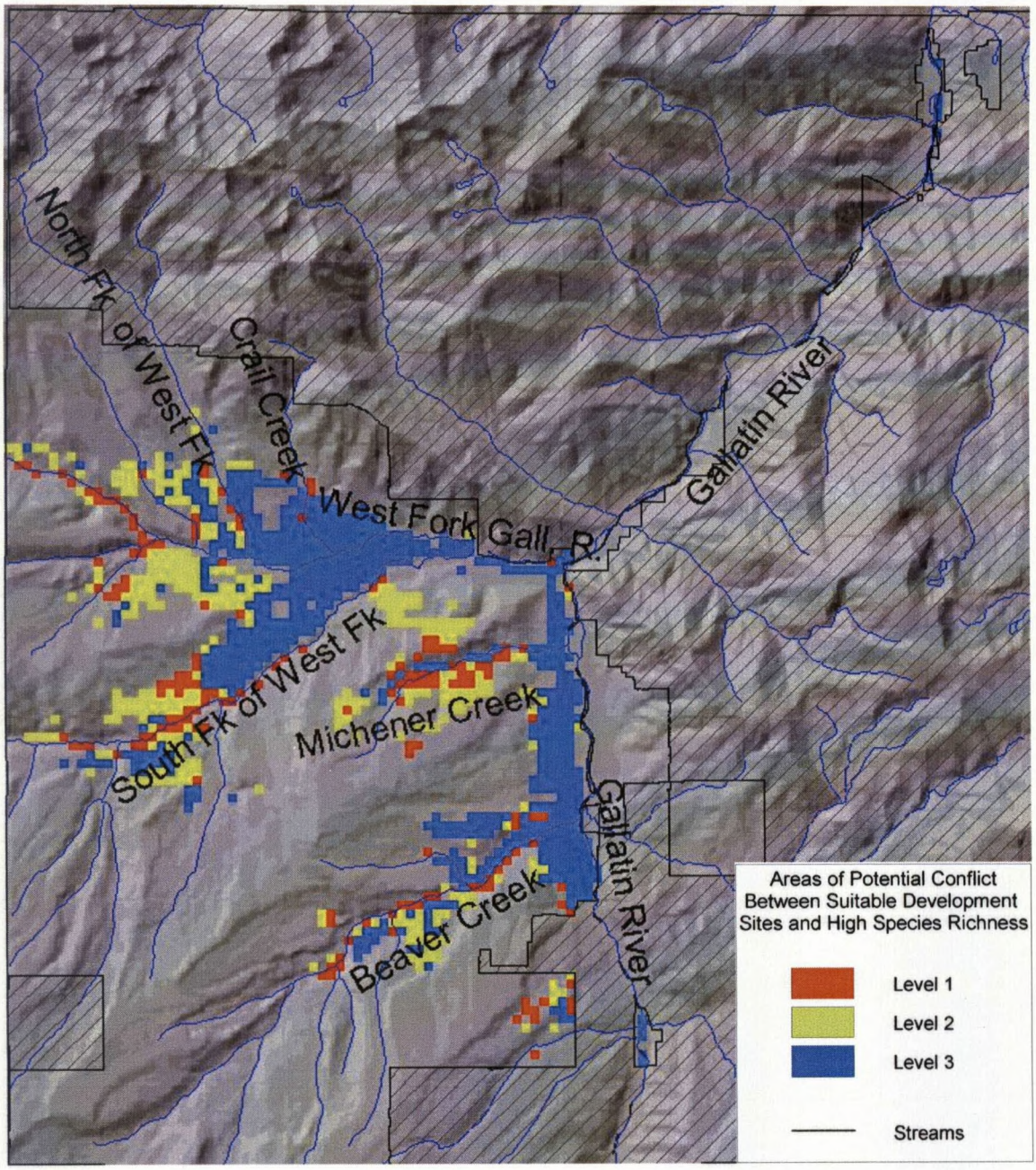


Figure 21. Areas of Potential Conflict –Species of Special Concern (Inclusive). Areas of potential conflict between suitable development sites and potential richness of species of special concern. Level 1 indicates areas with potential richness of 11-24 species; Level 2, 9-10 species; Level 3, 1-8 species. All levels have a Mahalanobis value of ≤ 15. Hashed areas are public lands.

Conflict Map – Species of Special Concern (Most Likely Subset)

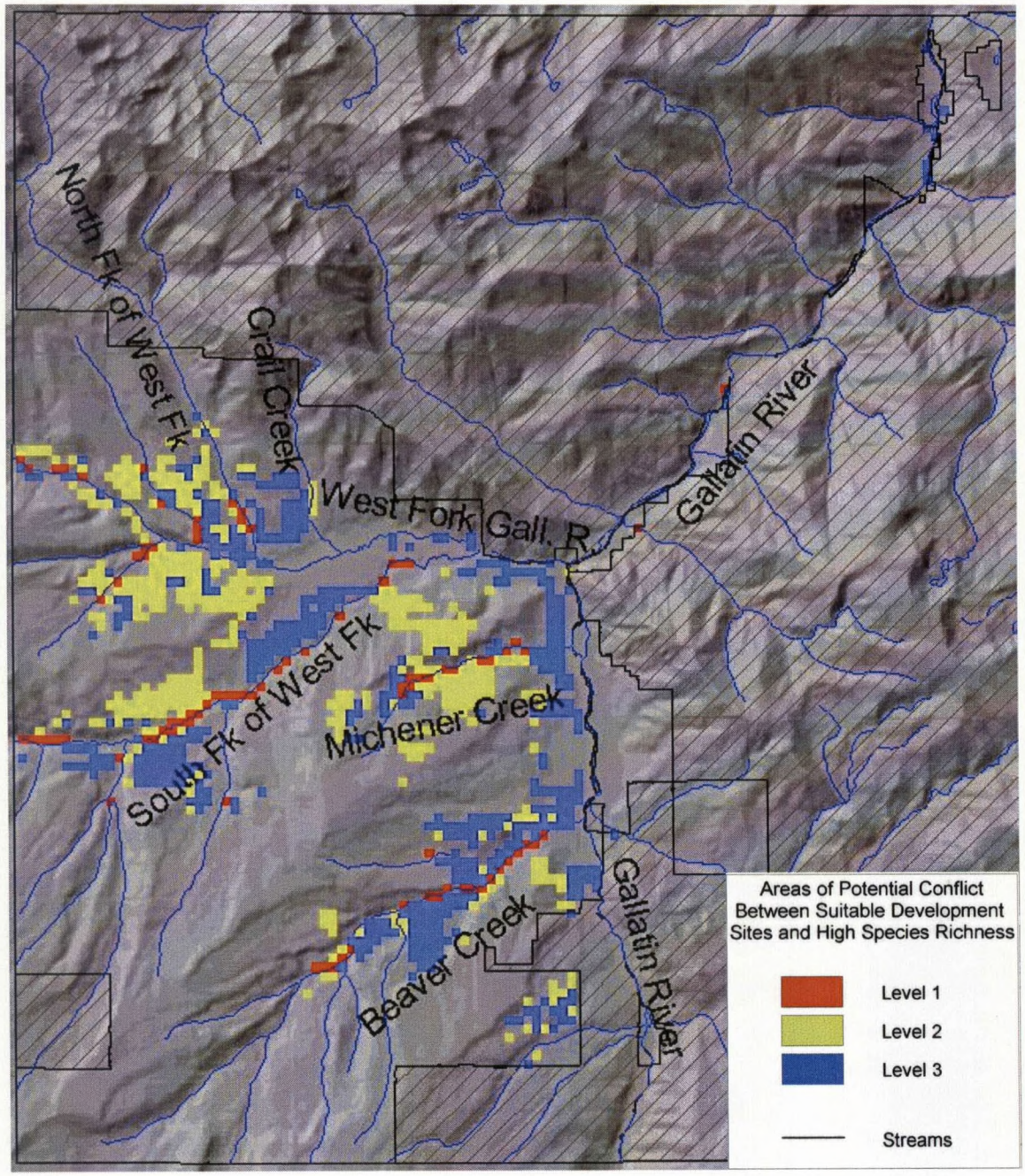


Figure 22. Areas of Potential Conflict –Species of Special Concern (Most Likely Subset). Areas of potential conflict between suitable development sites and potential richness of species of special concern. Level 1 indicates areas with potential richness of 9-10 species; Level 2, 8 species; Level 3, 1-7 species. All levels have a Mahalanobis value of ≤ 15. Hashed areas are public lands.

DISCUSSION

Vegetation Data and Accuracy Assessments

A common means of obtaining digital vegetation or land-cover data is through classification of remotely sensed imagery. The USGS' mapping standard for such data is 85% overall accuracy (Lillesand and Kiefer 1994). Applying this standard, the categorical assessment of the USDA FS vegetation classification and the re-coded GAP categories indicated that the overall accuracy of both coverages adequately represented the mosaic of plant communities across the landscape. Employing FS stand inventory maps in this situation was more cost-effective and convenient than creating a new dataset through remote sensing. Additionally, the Kappa analysis confirmed that no accuracy was lost during re-coding to the GAP categories, which allowed direct application of the GAP-developed species distribution models. The grouping of vegetation categories for the Mahalanobis distance analysis effectively increased the categorical accuracy of the vegetation data by lumping categories that had misclassifications within them. For example, Douglas-fir misclassified as lodgepole pine was no longer an error when the two categories were grouped as conifer.

Although the categorical accuracy of the stand inventory maps was acceptable, one problem was the lack of a minimum mapping unit (mmu). With satellite imagery, any object on the ground that is larger than the mmu will be represented by one or more pixels. This was not the case with the stand inventory maps. Without a defined mmu, the user cannot know the resolution of the mapping, nor that the resolution is standard across the mapped area. The smallest USDA FS classified vegetation polygon in the study area

was ~0.12 ha, but this did not ensure that all vegetation patches of this size or larger were represented. For example, a small marsh within a lodgepole stand might easily have been included in the lodgepole polygon, while another marsh of the same size might have been delineated as its own polygon. It was also possible that non-timber vegetation types were less carefully mapped than those that were of commercial interest. This conjecture was supported by comparing the amount of land in the study area classified as riparian and broadleaf cover types by the USDA FS and MT GAP. The stand inventory resulted in ~98 ha of riparian cover and ~522 ha of broadleaf cover, while MT GAP resulted in 528 ha for riparian and 1248 ha for broadleaf. Lower mapping accuracy of non-timber vegetation types would be evidenced by higher omission and commission rates for those individual categories. However, the omission and commission errors for individual categories were not robust due to small sample sizes within them.

The spatial accuracy assessment highlighted the spatial discrepancy between the orthophotographs and the vegetation coverage, exemplifying a problem with analyses that utilize multiple sources of digital data. There were errors inherent in digital data sources and additional errors when these sources were combined. In response to the spatial discrepancy, I chose to convert point locations to 150-m cells. This method *effectively* buffered the location of a building and had several consequences. Because a point was made of x and y coordinates, intersection of that point with all data layers to extract data for correlation testing and modeling would have required exact spatial agreement among all layers. Converting to an area that included a point allowed for some spatial discrepancy while increasing the chances that the true data variables from other layers were represented. This method also caused smoothing of the data when the

values of several adjacent cells were averaged. This generalizing could increase the robustness of data as errors were muted by the values of other cells (Erikson et al. 1998). However, this generalization also caused some loss of precision, and might have resulted in a decreased chance of detecting a correlation between variables.

Modeling Potential Habitat and Species Richness

Species modeling in a pre-development scenario resulted in high estimates of overall species richness along watercourses, at lower elevations, and predominately on private lands. These results were not surprising as others have suggested that habitats with proximity to streams and at low elevation create a biotically productive environment, which seems to support a greater diversity of species (Hansen and Rotella 1999; Hansen et al. 2000). Additionally, in this ecosystem most public land was at high elevation with low biomass, leaving high biodiversity areas in private ownership (Bean and Wilcove 1997; Jenning 2000). In this study, the largest contiguous area of high species richness occurred in the lower drainage of the West Fork of the Gallatin River. This was the same area that saw the most impact due to human growth, which is not atypical for the Greater Yellowstone Ecosystem (Hansen and Rotella 1999). According to species modeling in the current vegetation scenario, considerable loss of potential species richness occurred in this area and others due to developmental impacts. Though field studies have seen an increase in overall species richness with moderate levels of development (golf courses, residential areas), the increase was coincident with a decrease in native species diversity (Blair 1996). Another study showed a positive correlation

between the number of native species in an area and the percent urban, suggesting that urban areas either increased diversity or were simply located in already diverse areas (Iverson and Prasad 1998). The modeling procedure in this study did predict the addition of non-natives and urban-associates, but not to the extent that the loss to natives was overwhelmed. Because the results of the models have not been field-verified, they should not be interpreted as absolute measures of species richness and change. Rather, they should be viewed as relative measures used to identify the relative productivity of different portions of the landscape and to assess impacts of development on these areas.

Changes in potential habitat from pre-development to current scenarios suggested that potential habitat for the large majority of species in the Big Sky planning district was adversely affected by development. When modeling species reactions in hypothetical, urbanizing landscapes, White et al. (1997) found no local extinctions, but rather overall losses of habitat, with amphibians and reptiles most affected, followed by mammals then birds. Herpetiles, 87% of which lost potential habitat is this study, were found to be the group least represented in Wyoming conservation areas (Jenning 2000).

In this study, loss of potential habitat as a result of development was most consistent across amphibian species. These species are dependent on proximity to water and, therefore, riparian areas. Amphibians are detrimentally affected by either conversion of native riparian vegetation to altered herbaceous vegetation or riparian degradation due to development. However, because most amphibians are so tightly associated with riparian zones, the persistence of some of these species could be accommodated by buffer strips around watercourses and/or stream quality regulations

and monitoring. In addition to maintaining wildlife habitat, buffers might preserve the ecological benefits conferred by riparian vegetation (Thibault 1997).

Most of the reptilian species also lost potential habitat. They, too, are associated with streams and lower elevations, and most are not urban-adaptable, resulting in a conflict of interest with development in these areas. However, because the home ranges of these species are small, a matrix of native vegetation in a suburban setting might accommodate persistence of some reptilian species. Most avian species lost potential habitat, but some species in this class are urban-associates or urban-adaptable and, therefore, benefit from development effects. These species, especially nest predators and brood parasites, can occur at high densities in developed areas and have a large negative impact on other species that inhabit surrounding areas still in native cover (Saab 1999). With reduced fitness, persistence of bird populations utilizing the urban fringe might then depend on immigration from nearby source habitats (Hansen and Rotella 1999).

Of the mammalian species, only some species of bats gained potential habitat. Of the 54 species that gained any potential habitat due to development, only one is non-aerial, suggesting that the vagility of these organisms might confer some adaptive qualities allowing them to cope with development effects. Species that lost the largest proportion of potential habitat were associated with stream habitats or grasslands, meadows, and shrubs, while those that gained the most were associated with a variety of habitats but were generally adaptable to developmental changes.

Despite concern for the contrary (Pendergast et al. 1993; Harcourt 1999), the pattern of overall potential species richness in this study was representative of the patterns of class-level potential richness and species of special concern, perhaps with the

exception of Mammalia. Additionally, the patterns of relative species richness did not differ greatly between the inclusive list of species and the subset of species most likely to exist in the study area. Therefore, inclusive, overall potential richness was an adequate representation of the potential vertebrate richness pattern in the study area. The pattern of potential mammalian richness was more dispersed than that of Amphibia, Reptilia, and Aves, though it generally followed the stream/low elevation associations that were apparent in the other classes. A possible cause of the dispersed richness pattern in Mammalia might have been the higher proportion of generalist and carnivorous species in that class. However, below-average richness values in developed areas suggested that most mammals, though perhaps generalist, were not urban-adaptable. On the other hand, Reptilia and Aves showed above class-average potential richness in developed areas, suggesting there were a fair number of urban-adaptable species in these two classes. Though most areas of high potential richness were found on private lands, there were many areas of high potential richness for special concern mammals on public lands, suggesting that management of these species could focus on public lands, without concern for private land development. However, of all species modeled, mammals have the largest home range requirements and need terrestrial migration and dispersal routes connecting suitable habitat. Sprawling development throughout adjacent drainages, particularly when in a linear clustered pattern (as along stream corridors), could effectively degrade the quality of habitat on surrounding public lands and decrease habitat connectivity (Theobald et al. 1997). It has also been argued that generalists and exotics (that tend to accompany urban impact) put pressure on specialists and natives,

likely reducing their fitness in surrounding areas and causing extirpation (Garrott et al. 1993).

Models developed by the MT GAP represented a synthesis of the best state of the knowledge for a wide diversity of species across a large geographic area, but were by nature simplified and general. Only the most well understood or restrictive needs of a species were utilized to predict potential distribution, and some requirements might have been omitted simply because the data for modeling were lacking. For example, avian species often respond more to the structure of forest rather than to the individual tree species within (Edwards et al. 1996), yet data for this requirement are often not available. Because species requirements were simplified, potential habitat was likely over-estimated. Studies have shown commission error rates were higher than omission error rates for wildlife-habitat-relationship models (Block et al. 1994, Edwards et al. 1996) – species were predicted to inhabit areas where they were not found. On the other hand, inadequacies in data classification or resolution would result in higher omission error rates. As in this study, if riparian areas (or other spatially restricted habitats) were underrepresented by the vegetation map, species that specialize in those habitats might, in turn, have been under-predicted. Also, area of potential habitat lost to a species might have been over-estimated due to the modeling procedure. For example, when a plot of land was converted from native grassland to urban classification, the modeling process required that it became unsuitable habitat for all but urban-tolerant species. However, that plot might still have contained enough native vegetation, or been surrounded by native vegetation such that it continued to be utilized by some grassland-associated species. For conservation purposes, it might be more desirable to over-predict potential

species distributions rather than to under-predict them. Despite problems with rule-based species modeling, a study validating the UT GAP models found overall accuracy to be acceptable for all taxonomic groups – highest for birds (90.6%) and lowest for amphibians (69.4%) (Edwards et al. 1996).

Rates of Urbanization and Impact on Vegetation

The annual rate of growth in the Big Sky Planing District as calculated in this study was considerably higher than the rates for the state of Montana, the Western region of the U.S., and the nation as a whole, according to numbers reported by the US Census Bureau. Over the 36-year interval, the number of buildings in the district grew at an annual rate of 4.7%, while the population of the state grew at 0.7%, the region at 2.0%, and the nation at 1.1%. Although this study focused on numbers of buildings and census data reflect numbers of people, it is reasonable that the results of this study represent a comparable estimate of the population growth for the district -- assuming that more than one person typically inhabits a residence, yet not all buildings are residences nor permanently occupied. In the absence of population data, building density, as used in this study, can be a surrogate for approximating human influence (Wear and Boldtad 1998).

Of the 963 buildings in the study area, 27% were built between 1971 and 1981. This period coincided with the establishment of the Big Sky Ski and Summer Resort, implying that the resort was a major draw to the area in terms of permanent residences, vacation homes, and businesses. The resort provided access to recreation and scenic vistas in a landscape that rated high in 'quality of life' amenities and in an ecosystem that drew businesses and people interested in those same amenities (Johnson and Rasker

1995). The conflict between a high, sustained growth rate and protection of quality of life has been noted in more remote areas of Appalachia where growth rates were also high (Wear and Bolstad 1998). Allowing development to continue unchecked will have negative consequences on the quality of life amenities in the Big Sky area, including native vegetation and the wildlife community that depends on it. On the other hand, analyzing human growth patterns can help identify areas in the landscape where research or conservation efforts might be best directed.

The pattern of development in the Big Sky planning district showed that humans impacted different vegetative communities to different extents. Grasslands, meadows, shrublands, and riparian zones were used more than expected based on availability. Although low/moderate cover grassland absorbed the majority of development impacts, the percent conversion was highest for mixed xeric shrub and riparian cover types where nearly the total amount available was converted to civil. The area mapped for these cover types was low, however, and certainly under-represented their extent in the landscape. To better assess the true impact on these habitats, a concerted mapping effort would need to be undertaken for these non-timber vegetation types.

In this study, impacts on native vegetation were quantified by analyzing only those areas that the USDA FS had classified as civil in their vegetation map. These areas ranged from polygons with the only noticeable impact being transmission lines and disturbed ground, to high-density residential developments, to a golf course. The impact on vegetation in these cases was obviously variable. It can be argued that transmission lines alone have little impact on the vegetation of a plot of ground. Though this might be not be completely true with the spread of non-native plants, the degree of impact was

certainly less than in a residential community where only the mature tree species might remain, or on a golf course where non-native grasses completely replaced what was once native vegetation. However, I contend that the impact on vegetation in the Big Sky district was actually underestimated. Of the 963 buildings present in 1998, only 635 of them were located in a polygon considered civil on the USDA FS map (Figure 23). The impact of the remaining 328 buildings was not quantified.

Additionally, extensive logging in the district has left road networks throughout both public and private lands (Figure 23). Not all roads were maintained, however, making permanent impacts difficult to assess. Nonetheless, impacts due to roads, even if only used as hiking and biking trails, were not insignificant to wildlife species and should be considered when assessing developmental impacts (Miller 1998). A study assessing land-use change from 1950 to 1990 found that a road network existing in 1950 persisted over time with considerable expansion, and that road-building for one purpose (i.e., logging) can have significant influence on future land use (Wear and Bolstad 1998).

Human impact on particular vegetation types was not likely a direct consequence of vegetation, but rather a result of the economics of development. Roads tended to follow natural watercourses, which put access for development in riparian zones and the vegetative communities surrounding them. Low elevation and low slope also reduced the cost of development while being correlated with certain vegetation types. Thus, while humans might not have intentionally impacted certain vegetation types when selecting building locations, the impacts were disproportionate nonetheless.

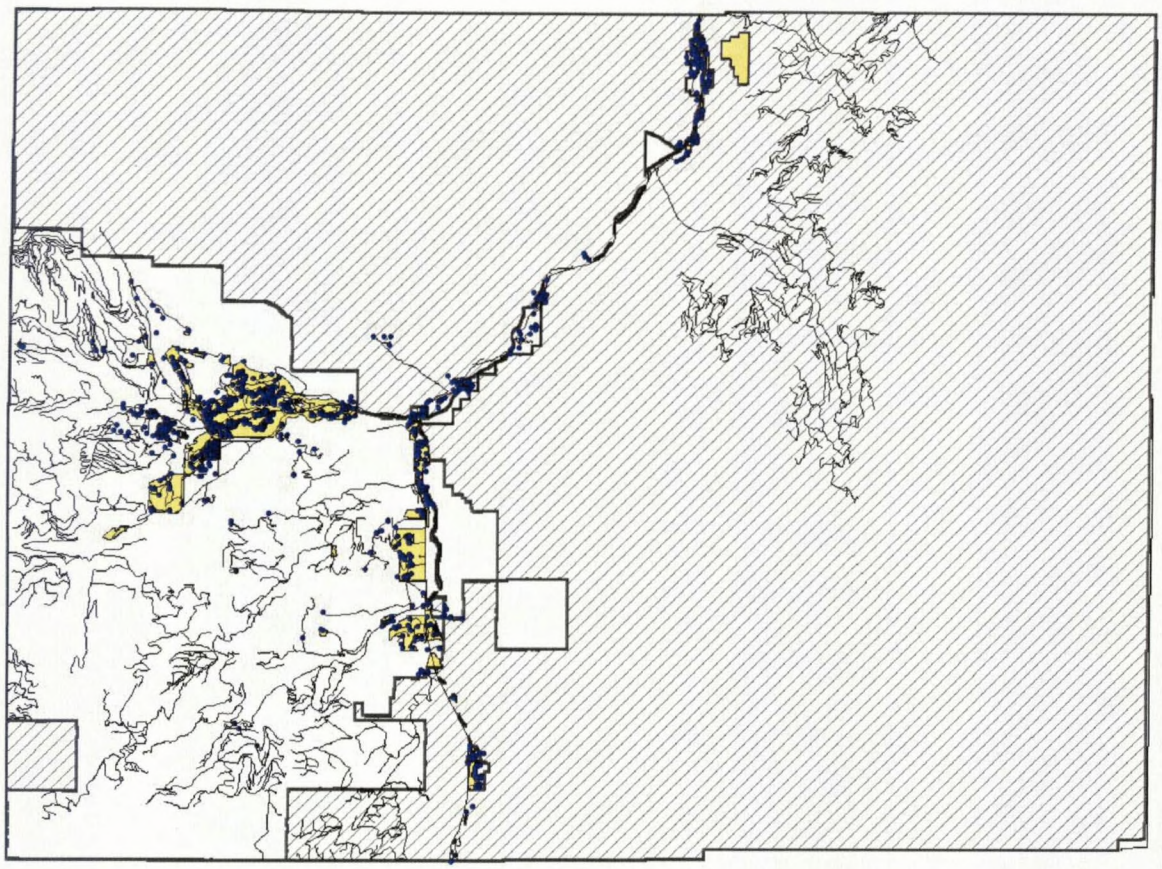


Figure 23. Building Locations and Road Networks. Roads represent all permanent and logging roads in the study area. Highlighted polygons represent those areas considered "civil" by the USDA FS digital landcover map. Hashed area is public land, while un-hashed is private.

Along with influencing vegetation types, slope and elevation were correlated with building locations. This finding was not unique, as it has been suggested by other studies (Wear and Flamm 1993; Turner et al. 1996; Wear and Bolstad 1998). Building locations were negatively associated with both distance to roads and distance to streams. This finding was expected, as roads tend to follow the topography created by streams, roads are the means of access for development as well as transport to market centers (Wear and Flamm 1993), and higher growth occurs where roads are more accessible (Poudevigne et

al. 1997). The percent vegetation-type variables that were also correlated with building locations might be explained in part by the elevational gradient. Building locations were positively associated with "%grass/shrub/meadow" and "%riparian", while negatively associated with "%conifer" and "%rock". In the study area, these cover types occurred at lower and higher elevations, respectively. There was also a negative association between building locations and "%deciduous", which was not expected, but might be the result of poor classification for this cover type. If deciduous was under-represented in the vegetation map (as suggested above, in comparison to the same cover type mapped by MT GAP), then the negative relationship might be erroneous. A concerted effort to map this cover type is needed to further test the relationship.

Potential Future Urbanization and Conflict Avoidance

The Mahalanobis distance statistic, based on the values of correlated variables for all cells with building density greater than zero, showed a reasonable pattern for future building locations. The pattern in Figure 15 resembled the result of common mechanisms by which growth occurs -- in-fill and sprawl (Stoms 2000). If development clustered around and spread from present building locations and existing roads (as suggested by the positive correlation between building presence and neighborhood density and the negative correlation with distance to road), future patterns in the West Fork of the Gallatin River might look very much like the Mahalanobis values suggested. In addition to these impacts, new development was likely in the less developed drainages of the South Fork of the West Fork, Mitchener Creek and Beaver Creak. These areas were also

highlighted on the maps of potential conflict (Figures 17-22) due to their high levels of species richness.

The maps of potential conflict were not meant to predict or forecast the future, but rather focus attention and future investigations on portions of the landscape that were potentially at risk. The species richness maps were the result of a rule-based modeling process and the Mahalanobis values were based on what has happened in the past, which might not represent what will occur in the future (Turner et al. 1996). The error involved in both of these methodologies was difficult to quantify, and neither result has been field-verified. However, the methods represented an educated and logical process that can aid in decision-making for the future of the Big Sky planning district. The Mahalanobis analysis was chosen over mechanism-driven statistical modeling options primarily because the likelihood that land will be developed depends on dynamic social and economic conditions, including population growth, tax incentives, and technological advances, and on choices made by individuals (Turner et al. 1996; Stoms 2000). These factors were complex and unpredictable, making data acquisition and model parameterization difficult. If the Big Sky community chooses to protect certain habitats, the maps of potential conflict created through my methodology should provide them with at least suggestions for focused action.

A potential problem with the multivariate nature of the Mahalanobis distance is that it was possible for a cell to be considered suitable for development even if that cell's value for one variable would cause it, in truth, to be unsuitable. For example, a slope greater than 45% might be considered unsuitable for development regardless of the values of the other variables. However, the Mahalanobis value for that location could

still be low, indicating suitability. To improve the method, thresholds could be employed such that a cell would become unsuitable if a variable value fell outside the acceptable range. The results of the method might also improve if the building pattern at each time period was analyzed separately. This would allow investigation of the change in building pattern through time, as well as changes in significant predictors of development.

Scope and Limitations

As with any research project, there are several conclusions drawn at the end of a study that would have improved that study. In this case, the first improvement on the results would come from a field-verification of the potential species distribution maps. All results concerning potential distributions, potential richness, and area of potential conflict depended directly on the quality of the Montana Gap Analysis Project's species-habitat models. It has been recommended that GAP models are appropriate for landscape-scale analysis, but not local scale (Edwards et al. 1996). Field sampling at several sites in different seasons would provide data to assess the accuracy of the species models, providing at least a measure of the omission and commission rates by taxonomic group.

Second, species richness assessments could have been improved if conservation value of individual species had been assigned. Though this is somewhat subjective and depends on availability of data, it allows for a more meaningful richness measure. Data useful for value assessment would provide information on rarity, endangered species status, endemism, susceptibility to urban pressure, regional population status, socio-

economic value, home range size, rare and threatened habitats, and patch size, among other concerns (Daniels et al 1991; Hansen et al. 1993; Raal and Burns 1996; Lee et al. 1999). Vertebrate richness would also be complemented by the addition of both plant and invertebrate richness measures to obtain a truer assessment of biodiversity (Daniels et al. 1991).

Third, a concerted effort should be made to map those non-timber vegetation types that are both rare in the landscape and important ecologically, i.e., riparian zones, broadleaf forest, and meadows – particularly in areas of potential conflict with future urbanization. If protection of these habitats becomes a priority, it will be imperative that they are well inventoried. Any major changes in vegetation can be tracked by updating the vegetation coverage, as well as changes in the building database. Updating databases with time will allow on-going analyses of both human growth patterns and the impacts on habitat and wildlife communities. Fourth, additional analyses should be conducted to assess the effect of the extensive road network on wildlife habitat. Data on road usage would be necessary at the very least. Although a field study might be appropriate, there is a body of literature on the effects of roads on wildlife that could be useful in a modeling effort.

Finally, I would to stress some of the limitations of the methods, data availability, and, consequently, the results of this thesis. All species distributions modeled through the Gap Analysis Project methods are *potential distributions*. The models for many species are very simple due either to a lack of knowledge of a given species' habitat needs or the lack of data to model those needs. Because site-specific data on the

composition of the vertebrate community were not available, I chose to create an inclusive list of species to model, and from that list I created the subset of species most likely to exist in the study area. Inclusion in either list does not imply that the species actually exists in the study area. The requirement for inclusion in the most likely subset of species was that there was strong evidence for the species presence, for the most part, in the Bozeman latilong. Because of the large geographic area that the latilong covers, it is likely that some species with strong evidence of presence still do not exist in the study area. Users of this thesis are recommended to take careful note of the species modeled and the evidence of presence associated with each, found in Appendix C. Despite these caveats, I would ask users of this thesis also to note the similarity of pattern in the species richness maps, whether overall, class-level, special concern status, inclusive, or subset. These maps have been colored using a uniform methodology such that relative richness can be compared. This comparison identifies locations and landscape features at those locations that consistently express high levels of potential species richness, regardless of which individual species actually exist there.

Concluding Remarks

GIS analyses of species richness hot spots and human use of the environment on a local scale make it evident that productive areas in the landscape are attractive to a majority of species, including humans. Vegetation that occurs in areas of low elevation, low grade, and proximity to water are impacted by human development more than expected based on their availability. These same areas are appropriate habitat for a

diversity of wildlife species. To protect biodiversity, we need to strive for a functioning ecosystem with all native habitats represented (O'Neil et al. 1995). This might mean identifying important ecological areas and actively protecting them not only from conversion to civil use but also from the ill-effects of nearby civil areas (spread of exotics, run-off, erosion, noise, and pollution) that contribute to the cumulative effects of development. The best protection might come in the form of zoning or land acquisition (Rodiek and Bolen 1997). Given that humans are as adaptable and reasonable as we are, that our population continues to grow, and that conversion of native habitat to an urban landscape is effectively an irreversible and permanent disturbance, knowledge of the patterns of human settlement should be incorporated into our considerations of urban planning as well as conservation of biodiversity.

This incorporation requires a landscape-level, interdisciplinary approach to management. The 'big-picture' awareness that encompasses the needs of humans and the ecosystems in which we live has been termed 'ecosystem management' or sustainable management. Within ecosystem management, the sciences of biology, ecology, agriculture, sociology, economics, and urban planning must interact. The conflict between growing human societies and the preservation of natural habitats and biodiversity can only be solved by understanding the socioeconomics of urban development and sprawl, the influence of environmental factors on urban development, the impacts of development on habitats and associated biodiversity, and the requirements of healthy, functioning ecosystems. Ultimately, suggestions can be made for future planning to minimize these impacts and achieve common goals.

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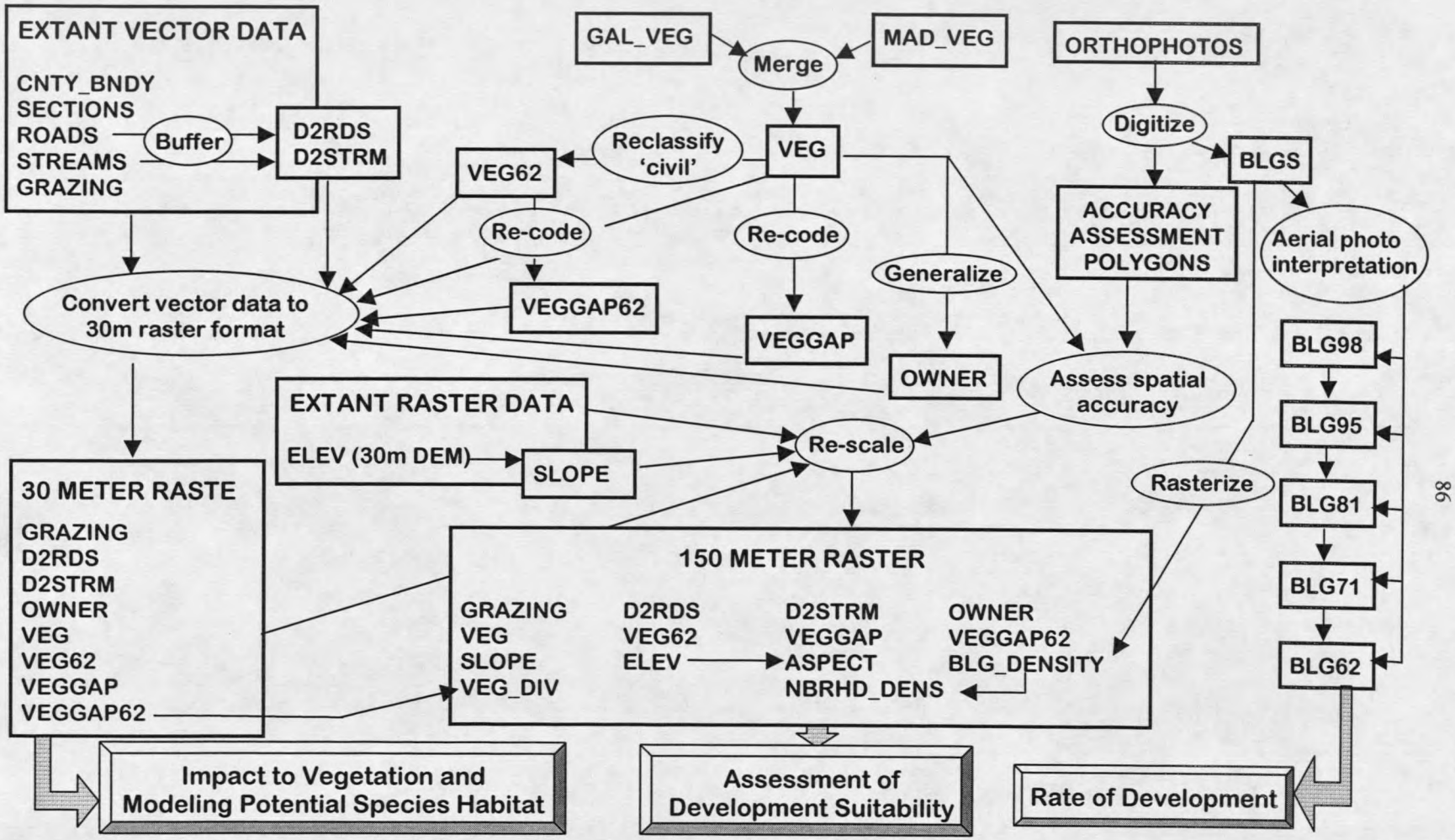
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APPENDICES

APPENDIX A

Appendix A: Descriptions and Flowchart of GIS Data Layers Obtained, Manipulated, Created, and/or Used in Project Analyses.

DATA LAYER	DESCRIPTION
CNTY_BNDY	Gallatin County Boundary
SECTIONS	Township/Range Sections
ROADS	Roads – paved and unpaved
D2RDS	Distance to nearest road
STREAMS	Streams
D2STRM	Distance to nearest stream
GRAZING	Grazing status – grazed or not grazed
OWNER	Ownership – public (USDA FS) or private
GAL_VEG	Gallatin Range vegetation layer – USDA FS categories
MAD_VEG	Madison Range vegetation layer – USDA FS categories
VEG	Merged vegetation layer – USDA FS categories
VEG62	Pre-development vegetation layer ('civil' polygons re-classified to native vegetation via aerial photo interpretation) – USDA FS categories
VEGGAP	Merged vegetation layer re-coded with MT GAP vegetation categories
VEGGAP62	Pre-development vegetation layer ('urban' polygons re-classified to native vegetation via aerial photo interpretation) – MT GAP categories
ELEV	30m Digital Elevation Model
SLOPE	Slope calculated from the DEM
ASPECT	Aspect calculated from the DEM
BLGS	All building locations digitized from orthophotogaraphs
BLG98	Buildings present in 1998
BLG95	Buildings present in 1995 (identified on 1995 aerial photographs)
BLG81	Buildings present in 1981 (identified on 1981 aerial photographs)
BLG71	Buildings present in 1971 (identified on 1971 aerial photographs)
BLG62	Buildings present in 1962 (identified on 1962 aerial photographs)
BLG_DENSITY	Number of buildings per hectare calculated for each 150m cell
NBRHD_DENS	Number of buildings per hectare within the 9 cell window centered on each 150m cell



Appendix A (continued). Flow chart of extant, manipulated, and created data layers used to assess the impact of development on native vegetation, to model potential species habitat and richness, to assess suitability for future development, and to assess the rate of development in the Gallatin Canyon/Big Sky planning district, Gallatin County, MT. Data layers are boxed; actions are circled.

APPENDIX B

Appendix B: Vegetation Reclassification Table

Table defining the reclassification scheme used to convert USDA FS cover types to MT GAP cover types. Vegetation codes and cover types used by the USDA FS Timber Stand Management Record System are listed in the first column. Middle and right columns display the codes and cover types defined by the Montana Gap Analysis Project. The USDA FS cover types are unique classifications for the Gallatin NF. Complete descriptions of MT GAP classifications can be found in Hart, et al. (1998).

USDA FS Codes and Stratum Names	MT GAP Codes	MT GAP Cover Types
00011 - tall willow	6120	Broadleaf Riparian
00012 - moist sagebrush/cinquefoil shrub meadow	3210	Mixed Mesic Shrubs
00013 - dry sagebrush shrubland	3300	Mixed Xeric Shrubs
00014 - low willow	6300	Shrub Riparian
00015 - moist rocky sagebrush shrubland	N/A*	
00021 - forb dominated seep	6200	Graminoid and Forb Riparian
00022 - wet forb meadow	3180	Montane Parklands and Subalpine Meadows
00023 - moist forb meadow	3180	Montane Parklands and Subalpine Meadows
00024 - dry forb meadow	3150	Low/Moderate Cover Grasslands
00031 - marsh and fen	6200	Graminoid and Forb Riparian
00032 - wet grassland and meadow	3170	Moderate/High Cover Grasslands
00033 - moist grassland and meadow	3170	Moderate/High Cover Grasslands
00034 - high elevation rocky grassland	8100	Alpine Meadows
00035 - dry grassland and meadow	3150	Low/Moderate Cover Grasslands
00041 - wet forest opening (<5 acres)	3180	Montane Parklands and Subalpine Meadows
00042 - moist to dry forest opening (<5 acres)	3150	Low/Moderate Cover Grasslands
00051 - tundra	*N/A	
00052 - exposed bedrock (slab rock or exposed soil)	7300	Rock
00053 - talus	7300	Rock
00054 - streamcourse	5000	Water
00055 - open water	5000	Water

Appendix B (continued): Vegetation Reclassification Table

USDA FS Codes and Stratum Names	MT GAP Codes	MT GAP Cover Types
00056 - cliffs	7300	Rock
00057 - avalanche chute (shrub dominated)	7300	Rock
00058 - avalanche chute (grass/forb dominated)	7300	Rock
00059 - agricultural lands	*N/A	
00060 - civilized areas	1100	Urban or Developed Lands
QA - quaking aspen	4140	Mixed Broadleaf Forest
PF - limber pine	4205	Limber Pine
CW - cottonwood	*N/A	
J - juniper	4214	Rocky Mountain Juniper
PG - pigmy forests	*N/A	
KR - krumholtz	4270	Mixed Subalpine Forest
WB - whitebark pine	4260	Mixed Whitebark Pine Forest
DF = Douglas-fir	4212	Douglas-fir
LP = lodgepole pine	4203	Lodgepole Pine
SAF = subalpine fir and spruce	4270	Mixed Subalpine Forest
PP = ponderosa pine	4206	Ponderosa Pine
LPDF = lodgepole pine and Douglas-fir	4223	Douglas-fir/Lodgepole Pine

*N/A = No such polygons in study area

APPENDIX C

Appendix C: Change in Potential Habitat for All Modeled Species

Change in the amount of potential habitat for modeled species. Change is assessed as the difference in potential distribution for each species from pre-development conditions to current conditions. Species in bold-faced font are species of special concern. STAT code represents the likelihood of presence in the study area for each species, as well as documentation of source information. Capital letters, *, and $ represent species more likely to be present in the study area.

STAT codes, documentation, and location of reference information for Amphibia, Reptilia, and Mammalia are as follows:

S = Specimen documented and deposited in public museum or university – Thompson 1982. Bozeman latilong.
V = Visual or auditory evidence; specimen in private museum, collection, or non-university government agency; photographs, tracks, or sign – Thompson 1982. Bozeman latilong.
? = Questionable record; not confirmed – Thompson 1982. Bozeman latilong.
* = Present – Heath 1973. Gallatin Mountains, Gallatin County.
$ = Present – Cramer 1992. Gallatin Mountains, Gallatin County.
H = Huntable population – Picton 1976. Gallatin canyon.
E = Observed – Picton 1976. Gallatin canyon.
A = Archival data – Picton 1976. Gallatin canyon.
g = Habitat predicted nearby – Hart et al. 1998. MT GAP results.

STAT codes, documentation, and location of reference information for Aves are as follows:

B = Direct evidence of breeding – Bergeron et al. 1992. Bozeman latilong.
b = Indirect evidence of breeding – Bergeron et al. 1992. Bozeman latilong.
t = Observed, no evidence of breeding – Bergeron et al. 1992. Bozeman latilong.
W = Overwintering – Bergeron et al. 1992. Bozeman latilong.
w = Observed during winter, no evidence of overwintering – Bergeron et al. 1992. Bozeman latilong.
g = Habitat predicted nearby – Hart et al. 1998. MT GAP results.

AMPHIBIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Anura	Bufonidae	Bufo	boreas	weto	Western (Boreal) Toad	-	1-25	0	-3	0	S
Anura	Hylidae	Pseudacris	triseriata	wcfr	Western Chorus Frog	0	0	0	0	0	V
Anura	Pelobatidae	Spea	bombifrons	plsp	Plains Spadefoot	-	500-600	0	-522	-32	S
Anura	Ranidae	Rana	luteiventris	csfr	Columbia Spotted Frog	-	100-200	0	-170	-3	S
Anura	**Ranidae**	**Rana**	**pipiens**	**nlfr**	**Northern Leopard Frog**	**-**	**100-200**	**0**	**-170**	**-7**	**S**
Caudata	Ambystomatidae	Ambystoma	tigrinum	tisa	Tiger Salamander	-	1-25	0	-3	0	S

REPTILIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Squamata	Boidae	Charina	bottae	rubo	Rubber Boa	-	1-25	0	-3	0	S
Squamata	Colubridae	Pituophis	melanoleucus	gosn	Gopher Snake	-	700-800	0	-765	-8	S
Squamata	Colubridae	Coluber	constrictor	race	Racer	-	600-700	0	-690	-19	S
Squamata	Colubridae	Thamnophis	elegans	wtgs	Western Terrestrial Garter Snake	-	1-25	0	-3	0	S
Squamata	Colubridae	Thamnophis	sirtalis	cgsn	Common Garter Snake	+	0	1-25	12	0	S
Squamata	Iguanidae	Phrynosoma	douglassii	shli	Short-Horned Lizard	-	600-700	0	-646	-25	S
Squamata	Phrynosomatidae	Sceloporus	graciosus	sali	Sagebrush Lizard	-	600-700	0	-676	-21	g
Squamata	Viperidae	Crotalus	viridis	wera	Western Rattlesnake	-	700-800	0	-766	-8	S

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Anseriformes	Anatidae	Aythya	marila	grsc	Greater Scaup	0	0	0	0	0	t
Anseriformes	Anatidae	Aythya	valisineria	canv	Canvasback	-	100-200	0	-124	-22	t W
Anseriformes	Anatidae	Branta	canadensis	cago	Canada Goose	-	600-700	0	-685	-21	B W
Anseriformes	Anatidae	Oxyura	jamaicensis	rudu	Ruddy Duck	-	100-200	0	-133	-19	B w
Anseriformes	Anatidae	Anas	discors	bwte	Blue-Winged Teal	-	500-600	0	-531	-18	B w
Anseriformes	Anatidae	Anas	cyanoptera	cite	Cinnamon Teal	-	500-600	0	-531	-18	B
Anseriformes	Anatidae	Anas	acuta	nopi	Northern Pintail	-	600-700	0	-653	-18	B W
Anseriformes	Anatidae	Anas	platyrhynchos	mall	Mallard	-	500-600	0	-500	-18	B W
Anseriformes	Anatidae	Aythya	americana	redh	Redhead	-	500-600	0	-500	-18	B w
Anseriformes	Anatidae	Anas	americana	amwi	American Wigeon	-	500-600	0	-579	-18	B W
Anseriformes	Anatidae	Anas	crecca	gwte	Green-Winged Teal	-	500-600	0	-546	-18	B W
Anseriformes	Anatidae	Anas	strepera	gadw	Gadwall	-	500-600	0	-514	-17	B W
Anseriformes	Anatidae	Chen	rossii	rogo	Ross's Goose	-	600-700	0	-658	-17	t
Anseriformes	Anatidae	Chen	caerulescens	sngo	Snow Goose	-	600-700	0	-658	-17	t w
Anseriformes	Anatidae	Anser	albifrons	gwfg	Greater White-Fronted Goose	-	600-700	0	-628	-17	t
Anseriformes	Anatidae	Anas	clypeata	nosh	Northern Shoveler	-	500-600	0	-545	-16	B W
Anseriformes	**Anatidae**	**Cygnus**	**buccinator**	**trsw**	**Trumpeter Swan**	**-**	**25-50**	**0**	**-29**	**-11**	**B W**
Anseriformes	Anatidae	Aythya	collaris	rndu	Ring-Necked Duck	-	1-25	0	-18	-8	b w
Anseriformes	Anatidae	Mergus	serrator	rbme	Red-Breasted Merganser	-	1-25	0	-9	-6	t w
Anseriformes	Anatidae	Aythya	affinis	lesc	Lesser Scaup	-	25-50	0	-37	-4	b W
Anseriformes	Anatidae	Bucephala	islandica	bago	Barrow's Goldeneye	-	100-200	0	-121	-2	t W

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Anseriformes	Anatidae	Aix	sponsa	wodu	Wood Duck	-	1-25	0	-10	-2	B w
Anseriformes	**Anatidae**	**Histrionicus**	**histrionicus**	**hadu**	**Harlequin Duck**	**-**	**25-50**	**0**	**-31**	**-2**	**b**
Anseriformes	Anatidae	Bucephala	albeola	buff	Bufflehead	-	50-100	0	-95	0	t W
Anseriformes	Anatidae	Bucephala	clangula	cogo	Common Goldeneye	-	50-100	0	-78	0	t W
Anseriformes	Anatidae	Mergus	merganser	come	Common Merganser	-	50-100	0	-70	0	B W
Anseriformes	Anatidae	Lophodytes	cucullatus	home	Hooded Merganser	-	50-100	0	-86	0	B w
Anseriformes	Anatidae	Cygnus	columbianus	tusw	Tundra Swan	+	0	1-25	2	0	t w
Apodiformes	**Apodidae**	**Cypseloides**	**niger**	**blsw**	**Black Swift**	**0**	**0**	**0**	**0**	**0**	**t**
Apodiformes	Apodidae	Aeronautes	saxatalis	wtsw	White-Throated Swift	-	100-200	0	-108	0	b
Apodiformes	Apodidae	Chaetura	pelagica	chsw	Chimney Swift	+	0	700-800	769	1582	t
Apodiformes	Trochilidae	Archilochus	alexandri	bchu	Black-Chinned Hummingbird	-	25-50	0	-32	-4	t
Apodiformes	Trochilidae	Selasphorus	rufus	ruhu	Rufous Hummingbird	-	100-200	0	-128	-2	t
Apodiformes	Trochilidae	Stellula	calliope	cahu	Calliope Hummingbird	+	0	600-700	648	4	b
Caprimulgiformes	Caprimulgidae	Chordeiles	minor	coni	Common Nighthawk	-	600-700	0	-662	-17	B
Caprimulgiformes	Caprimulgidae	Phalaenoptilus	nuttallii	cpoo	Common Poorwill	-	1-25	0	-15	-4	t
Charadriiformes	Charadriidae	Charadrius	semipalmatus	sepl	Semipalmated Plover	-	100-200	0	-124	-22	t
Charadriiformes	Charadriidae	Pluvialis	squatarola	bbpl	Black-Bellied Plover	-	100-200	0	-130	-19	t
Charadriiformes	Charadriidae	Charadrius	vociferus	kill	Killdeer	+	0	700-800	769	236	B W
Charadriiformes	**Laridae**	**Sterna**	**caspia**	**cate**	**Caspian Tern**	**0**	**0**	**0**	**0**	**0**	**t**
Charadriiformes	**Laridae**	**Sterna**	**forsteri**	**fote**	**Foster's Tern**	**0**	**0**	**0**	**0**	**0**	**t**
Charadriiformes	**Laridae**	**Larus**	**pipixcan**	**frgu**	**Franklin's Gull**	**-**	**500-600**	**0**	**-500**	**-18**	**t**

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Charadriiformes	Laridae	Larus	philadelphia	bogu	Bonaparte's Gull	-	500-600	0	-500	-18	t
Charadriiformes	**Laridae**	**Chlidonias**	**niger**	**blte**	**Black Tern**	**-**	**1-25**	**0**	**-9**	**-5**	**t**
Charadriiformes	Laridae	Larus	californicus	cagu	California Gull	+	0	100-200	117	5	t
Charadriiformes	Laridae	Larus	delawarensis	rbgu	Ring-Billed Gull	+	0	600-700	627	282	t
Charadriiformes	**Recurvirostridae**	**Himantopus**	**mexicanus**	**bnst**	**Black-Necked Stilt**	**0**	**0**	**0**	**0**	**0**	**t**
Charadriiformes	Recurvirostridae	Recurvirostra	americana	amav	American Avocet	-	100-200	0	-129	-23	B
Charadriiformes	Scolopacidae	Tringa	melanoleuca	grye	Greater Yellowlegs	0	0	0	0	0	t
Charadriiformes	Scolopacidae	Tringa	flavipes	leye	Lesser Yellowlegs	0	0	0	0	0	t
Charadriiformes	Scolopacidae	Phalaropus	tricolor	wiph	Wilson's Phalarope	-	100-200	0	-132	-25	B
Charadriiformes	Scolopacidae	Catoptrophorus	semipalmatus	will	Willet	-	500-600	0	-499	-21	B
Charadriiformes	Scolopacidae	Limosa	fedoa	mago	Marbled Godwit	-	500-600	0	-499	-21	b
Charadriiformes	Scolopacidae	Calidris	bairdii	basa	Baird's Sandpiper	-	100-200	0	-130	-19	t
Charadriiformes	Scolopacidae	Calidris	melanotus	pesa	Pectoral Sandpiper	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Calidris	pusilla	sesa	Semipalmated Sandpiper	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Calidris	himantopus	stsa	Stilt Sandpiper	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Calidris	mauri	wesa	Western Sandpiper	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Limnodromus	scolopaceus	lbdo	Long-Billed Dowitcher	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Limnodromus	griseus	sbdo	Short-Billed Dowitcher	-	100-200	0	-125	-18	t
Charadriiformes	Scolopacidae	Calidris	minutilla	lesa	Least Sandpiper	-	100-200	0	-133	-18	t
Charadriiformes	Scolopacidae	Calidris	fusciollis	wrsa	White-Rumped Sandpiper	-	100-200	0	-133	-18	t
Charadriiformes	Scolopacidae	Phalaropus	lobatus	reph	Red-Necked Phalarope	-	100-200	0	-122	-18	g

Appendix C: (continued)
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ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Charadriiformes	Scolopacidae	Actitis	macularia	spsa	Spotted Sandpiper	-	100-200	0	-158	-8	t
Charadriiformes	Scolopacidae	Tringa	solitaria	sosa	Solitary Sandpiper	-	1-25	0	-9	-5	t
Charadriiformes	Scolopacidae	Gallinago	gallinago	cosn	Common Snipe	-	1-25	0	-9	-4	t W
Charadriiformes	Scolopacidae	Bartramia	longicauda	upsa	Upland Sandpiper	-	1-25	0	-1	0	B
Ciconiiformes	**Ardeidae**	**Nycticorax**	**nycticorax**	**bcnh**	**Black-Crowned Night Heron**	**-**	**1-25**	**0**	**-18**	**-8**	**t**
Ciconiiformes	Ardeidae	Botaurus	lentiginosus	ambi	American Bittern	-	1-25	0	-13	-4	b
Ciconiiformes	Ardeidae	Ardea	herodias	gbhe	Great Blue Heron	-	50-100	0	-93	-2	B W
Ciconiiformes	Cathartidae	Cathartes	aura	tuvu	Turkey Vulture	-	700-800	0	-752	-6	b
Ciconiiformes	**Threskiornithidae**	**Plegadis**	**chihi**	**wfib**	**White-Faced Ibis**	**-**	**1-25**	**0**	**-9**	**-4**	**t**
Columbiformes	Columbidae	Zenaida	macroura	modo	Mourning Dove	+	0	50-100	77	2	t W
Columbiformes	Columbidae	Columba	livia	rodo	Rock Dove	+	0	500-600	544	1415	t W
Coraciiformes	Alcedinidae	Ceryle	alcyon	beki	Belted Kingfisher	-	50-100	0	-81	0	t W
Cuculiformes	**Cuculidae**	**Coccyzus**	**americanus**	**ybcu**	**Yellow-Billed Cuckoo**	**-**	**1-25**	**0**	**-16**	**-4**	**g**
Cuculiformes	Cuculidae	Coccyzus	erythropthalmus	bbcu	Black-Billed Cuckoo	-	1-25	0	-16	-4	b
Falconiformes	**Accipitridae**	**Buteo**	**regalis**	**feha**	**Ferruginous Hawk**	**-**	**600-700**	**0**	**-634**	**-22**	**t**
Falconiformes	Accipitridae	Buteo	lagopus	rlha	Rough-Legged Hawk	-	600-700	0	-662	-17	t W
Falconiformes	Accipitridae	Buteo	swainsoni	swha	Swainson's Hawk	-	600-700	0	-646	-16	B
Falconiformes	Accipitridae	Circus	cyaneus	noha	Northern Harrier	-	600-700	0	-685	-15	t W
Falconiformes	Accipitridae	Buteo	jamaicensis	rtha	Red-Tailed Hawk	-	700-800	0	-743	-7	t W
Falconiformes	Accipitridae	Buteo	platypterus	bwha	Broad-Winged Hawk	-	1-25	0	-16	-7	g
Falconiformes	**Accipitridae**	**Haliaeetus**	**leucocephalus**	**baea**	**Bald Eagle**	**-**	**50-100**	**0**	**-98**	**-2**	**B W**

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Falconiformes	Accipitridae	Accipiter	cooperii	coha	Cooper's Hawk	-	50-100	0	-96	-1	b W
Falconiformes	**Accipitridae**	**Accipiter**	**gentilis**	**nogo**	**Northern Goshawk**	**-**	**50-100**	**0**	**-77**	**0**	**B W**
Falconiformes	Accipitridae	Pandion	haliaetus	ospr	Osprey	-	1-25	0	-18	0	B
Falconiformes	Accipitridae	Aquila	chrysaetos	goea	Golden Eagle	-	1-25	0	-10	0	B W
Falconiformes	Accipitridae	Accipiter	striatus	ssha	Sharp-Shinned Hawk	+	0	600-700	679	3	t W
Falconiformes	Falconidae	Falco	rusticolus	gyrf	Gyrfalcon	-	600-700	0	-640	-17	t w
Falconiformes	Falconidae	Falco	mexicanus	prfa	Prairie Falcon	-	600-700	0	-676	-11	B W
Falconiformes	**Falconidae**	**Falco**	**peregrinus**	**pefa**	**Peregrine Falcon**	**-**	**600-700**	**0**	**-661**	**-10**	**B W**
Falconiformes	Falconidae	Falco	sparverius	amke	American Kestrel	-	>800	0	-812	-8	t W
Falconiformes	Falconidae	Falco	columbarius	merl	Merlin	-	700-800	0	-720	-8	b W
Galliformes	Phasianidae	Meleagris	gallopavo	witu	Wild Turkey	0	0	0	0	0	g
Galliformes	Phasianidae	Phasianus	colchicus	rnph	Ring-Necked Pheasant	-	600-700	0	-640	-17	B W
Galliformes	**Phasianidae**	**Tympanuchus**	**phasianellus**	**stgr**	**Sharp-Tailed Grouse**	**-**	**600-700**	**0**	**-655**	**-16**	**B W**
Galliformes	Phasianidae	Perdix	perdix	grpa	Gray Partridge	-	600-700	0	-654	-15	B W
Galliformes	Phasianidae	Centrocercus	urophasianus	sagr	Sage Grouse	-	1-25	0	-16	-3	B
Galliformes	Phasianidae	Alectoris	chukar	chuk	Chukar	-	1-25	0	-16	-3	b
Galliformes	Phasianidae	Dendragapus	obscurus	blgr	Blue Grouse	-	50-100	0	-86	-1	B W
Galliformes	Phasianidae	Bonasa	umbellus	rugr	Ruffed Grouse	-	50-100	0	-97	-1	B W
Gruiformes	Gruidae	Grus	canadensis	sacr	Sandhill Crane	-	25-50	0	-23	-5	B
Gruiformes	**Gruidae**	**Grus**	**americana**	**whcr**	**Whooping Crane**	**+**	**0**	**1-25**	**2**	**1**	**t**
Gruiformes	Rallidae	Fulica	americana	amco	American Coot	0	0	0	0	0	B w

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Gruiformes	Rallidae	Porzana	carolina	sora	Sora	-	25-50	0	-23	-5	t
Gruiformes	Rallidae	Rallus	limicola	vira	Virginia Rail	-	1-25	0	-9	-4	b
Passeriformes	Alaudidae	Eremophila	alpestris	hola	Horned Lark	-	25-50	0	-47	-2	B W
Passeriformes	Bombycillidae	Bombycilla	garrulus	bowa	Bohemian Waxwing	+	0	600-700	687	13	t W
Passeriformes	Bombycillidae	Bombycilla	cedrorum	cewa	Cedar Waxwing	+	0	100-200	153	188	B W
Passeriformes	Cardinalidae	Passerina	amoena	labu	Lazuli Bunting	-	100-200	0	-157	-18	b
Passeriformes	Cardinalidae	Pheucticus	melanocephalus	bhgr	Black-Headed Grosbeak	-	1-25	0	-16	-7	b
Passeriformes	Cardinalidae	Passerina	cyanea	inbu	Indigo Bunting	-	1-25	0	0	0	t
Passeriformes	Certhiidae	Certhia	americana	brcr	Brown Creeper	-	1-25	0	-22	0	b W
Passeriformes	Cinclidae	Cinclus	mexicanus	amdi	American Dipper	0	0	0	0	0	B W
Passeriformes	Corvidae	Gymnorhinus	cyanocephalus	pija	Pinyon Jay	0	0	0	0	0	B W
Passeriformes	Corvidae	Pica	pica	bbma	Black-Billed Magpie	-	25-50	0	-32	-6	B W
Passeriformes	Corvidae	Nucifraga	columbiana	clnu	Clark's Nutcracker	-	50-100	0	-81	-1	W
Passeriformes	Corvidae	Corvus	corax	cora	Common Raven	-	100-200	0	-127	-1	B W
Passeriformes	Corvidae	Cyanocitta	stelleri	stja	Steller's Jay	-	50-100	0	-90	0	B W
Passeriformes	Corvidae	Perisoreus	canadensis	grja	Gray Jay	-	1-25	0	-7	0	B W
Passeriformes	Corvidae	Corvus	brachyrhynchos	amcr	American Crow	+	0	100-200	130	3	B W
Passeriformes	Corvidae	Cyanocitta	cristata	blja	Blue Jay	+	0	700-800	776	679	t W
Passeriformes	Emberizidae	Calcarius	ornatus	cclo	Chestnut-Collared Longspur	-	600-700	0	-638	-20	b
Passeriformes	Emberizidae	Calcarius	lapponicus	lalo	Lapland Longspur	-	600-700	0	-638	-20	t W
Passeriformes	Emberizidae	Calcarius	mccownii	mclo	Mccown's Longspur	-	600-700	0	-638	-20	b

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Passeriformes	Emberizidae	Pooecetes	gramineus	vesp	Vesper Sparrow	-	600-700	0	-638	-20	B
Passeriformes	Emberizidae	Calamospiza	melanocorys	lbun	Lark Bunting	-	600-700	0	-653	-19	B
Passeriformes	Emberizidae	Chondestes	grammacus	lasp	Lark Sparrow	-	600-700	0	-631	-18	B
Passeriformes	Emberizidae	Plectrophenax	nivalis	snbu	Snow Bunting	-	600-700	0	-639	-17	t W
Passeriformes	Emberizidae	Passerculus	sandwichensis	sasp	Savannah Sparrow	-	600-700	0	-669	-17	B
Passeriformes	Emberizidae	Ammidramus	savannarum	grsp	Grasshopper Sparrow	-	600-700	0	-639	-17	b
Passeriformes	Emberizidae	Spizella	pallida	ccsp	Clay-Colored Sparrow	-	600-700	0	-646	-16	b
Passeriformes	Emberizidae	Pipilo	chlorurus	gtto	Green-Tailed Towhee	-	1-25	0	-16	-4	B
Passeriformes	Emberizidae	Spizella	breweri	brsp	Brewer's Sparrow	-	1-25	0	-16	-3	B
Passeriformes	Emberizidae	Pipilo	maculatus	spto	Spotted Towhee	-	1-25	0	-15	-3	g
Passeriformes	Emberizidae	Melospiza	lincolnii	lisp	Lincoln's Sparrow	-	25-50	0	-34	-1	b
Passeriformes	Emberizidae	Passerella	iliaca	fosp	Fox Sparrow	-	25-50	0	-44	-1	b
Passeriformes	Emberizidae	Spizella	passerina	chsp	Chipping Sparrow	-	50-100	0	-96	-1	B
Passeriformes	Emberizidae	Zonotrichia	leucophrys	wcsp	White-Crowned Sparrow	-	25-50	0	-32	-1	B
Passeriformes	Emberizidae	Junco	hyemalis	deju	Dark-Eyed Junco	-	100-200	0	-128	-1	B W
Passeriformes	Emberizidae	Spizella	arborea	atsp	American Tree Sparrow	+	0	100-200	129	3	t W
Passeriformes	Emberizidae	Melospiza	melodia	sosp	Song Sparrow	+	0	100-200	145	33	b W
Passeriformes	Emberizidae	Zonotrichia	querula	hasp	Harris's Sparrow	+	0	700-800	768	245	t W
Passeriformes	Emberizidae	Zonotrichia	albicollis	wtsp	White-Throated Sparrow	+	0	1-25	6	NA	t W
Passeriformes	Fringillidae	Leucosticte	atrata	brfi	Black Rosy-Finch	0	0	0	0	0	b W
Passeriformes	Fringillidae	Leucosticte	tephrocotis	gcrf	Gray-Crowned Rosy-Finch	0	0	0	0	0	t W

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Passeriformes	Fringillidae	Loxia	leucoptera	wwcr	White-Winged Crossbill	0	0	0	0	0	b W
Passeriformes	Fringillidae	Carduelis	hornemanni	hore	Hoary Redpoll	-	1-25	0	-16	-2	t W
Passeriformes	Fringillidae	Carpodacus	cassinii	cafi	Cassin's Finch	-	50-100	0	-77	-1	B W
Passeriformes	Fringillidae	Loxia	curvirostra	recr	Red Crossbill	-	50-100	0	-96	-1	B W
Passeriformes	Fringillidae	Pinicola	enucleator	pigr	Pine Grosbeak	-	50-100	0	-81	0	b W
Passeriformes	Fringillidae	Carduelis	pinus	pisi	Pine Siskin	+	0	600-700	678	3	B W
Passeriformes	Fringillidae	Carpodacus	mexicanus	hofi	House Finch	+	0	1-25	3	3	b W
Passeriformes	Fringillidae	Coccothraustes	vespertinus	evgr	Evening Grosbeak	+	0	600-700	694	5	B W
Passeriformes	Fringillidae	Carduelis	flammea	cred	Common Redpoll	+	0	700-800	753	111	t W
Passeriformes	Fringillidae	Carduelis	tristis	agol	American Goldfinch	+	0	500-600	557	411	B W
Passeriformes	Fringillidae	Carpodacus	purpureus	pufi	Purple Finch	+	0	700-800	753	587	t w
Passeriformes	Hirundinidae	Riparia	riparia	basw	Bank Swallow	-	600-700	0	-667	-19	B
Passeriformes	Hirundinidae	Stelgidopteryx	serripennis	nrws	N. Rough-Winged Swallow	-	600-700	0	-637	-18	B
Passeriformes	Hirundinidae	Hirundo	rustica	bswa	Barn Swallow	-	600-700	0	-632	-16	B
Passeriformes	Hirundinidae	Petrochelidon	pyrrhonota	clsw	Cliff Swallow	+	0	100-200	134	4	B
Passeriformes	Hirundinidae	Tachycineta	bicolor	tswa	Tree Swallow	+	0	600-700	672	12	B
Passeriformes	Hirundinidae	Tachycineta	thalassina	vgsw	Violet-Green Swallow	+	0	700-800	754	748	B
Passeriformes	Icteridae	Xanthocephalus	xanthocephalus	yhbl	Yellow-Headed Blackbird	0	0	0	0	0	B
Passeriformes	Icteridae	Dolichonyx	oryzivorus	bobo	Bobolink	-	600-700	0	-639	-17	b
Passeriformes	Icteridae	Sturnella	neglecta	weme	Western Meadowlark	-	600-700	0	-639	-17	B W
Passeriformes	Icteridae	Euphagus	carolinus	rubl	Rusty Blackbird	-	1-25	0	0	0	t W

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Passeriformes	Icteridae	Agelaius	phoeniceus	rwbl	Red-Winged Blackbird	-	1-25	0	-1	0	B W
Passeriformes	Icteridae	Icterus	bullockii	buor	Bullock's Oriole	+	0	600-700	621	359	B
Passeriformes	Icteridae	Quiscalus	quiscula	cogr	Common Grackle	+	0	700-800	768	377	B W
Passeriformes	Icteridae	Euphagus	cyanocephalus	brbl	Brewer's Blackbird	+	0	700-800	792	1104	B W
Passeriformes	Icteridae	Molothrus	ater	bhco	Brown-Headed Cowbird	+	0	>800	14064	NA	B
Passeriformes	Laniidae	Lanius	ludovicianus	losh	Loggerhead Shrike	-	25-50	0	-28	-4	B w
Passeriformes	Laniidae	Lanius	excubitor	nshr	Northern Shrike	-	25-50	0	-29	-3	t W
Passeriformes	Mimidae	Toxostoma	rufum	brth	Brown Thrasher	+	0	100-200	139	4	g
Passeriformes	Mimidae	Dumetella	carolinensis	grca	Gray Catbird	+	0	100-200	168	241	B
Passeriformes	Mimidae	Sturnus	vulgaris	eust	European Starling	+	0	>800	14221	12442	B W
Passeriformes	Motacillidae	Anthus	rubescens	apip	American Pipit	0	0	0	0	0	B
Passeriformes	Motacillidae	Anthus	spragueii	sppi	Sprague's Pipit	-	600-700	0	-638	-20	b
Passeriformes	Paridae	Poecile	gambeli	moch	Mountain Chickadee	-	50-100	0	-96	0	B W
Passeriformes	Paridae	Poecile	atricapillus	bcch	Black-Capped Chickadee	+	0	700-800	715	7	B W
Passeriformes	Parulidae	Dendroica	striata	blwa	Blackpoll Warbler	0	0	0	0	0	t
Passeriformes	Parulidae	Seiurus	noveboracensis	nowa	Northern Waterthrush	-	1-25	0	-16	-19	B
Passeriformes	Parulidae	Geothlypis	trichas	cyel	Common Yellowthroat	-	1-25	0	-9	-5	B
Passeriformes	Parulidae	Vermivora	celata	ocwa	Orange-Crowned Warbler	-	25-50	0	-30	-2	b
Passeriformes	Parulidae	Wilsonia	pusilla	wiwa	Wilson's Warbler	-	1-25	0	-13	-1	b
Passeriformes	Parulidae	Setophaga	ruticilla	amre	American Redstart	-	1-25	0	-1	-1	b
Passeriformes	Parulidae	Oporornis	tolmiei	mawa	Macgillivray's Warbler	-	25-50	0	-26	-1	B

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Passeriformes	Parulidae	Vermivora	ruficapilla	nawa	Nashville Warbler	-	1-25	0	-1	-1	t
Passeriformes	Parulidae	Vermivora	peregrina	tewa	Tennessee Warbler	-	1-25	0	-15	-1	t
Passeriformes	Parulidae	Seiurus	aurocapillus	oven	Ovenbird	-	1-25	0	0	0	b
Passeriformes	Parulidae	Dendroica	townsendi	towa	Townsend's Warbler	-	50-100	0	-96	0	t
Passeriformes	Parulidae	Dendroica	coronata	yrwa	Yellow-Rumped Warbler	-	50-100	0	-96	0	B w
Passeriformes	Parulidae	Dendroica	petechia	yewa	Yellow Warbler	+	0	100-200	168	241	B
Passeriformes	Passeridae	Passer	domesticus	hosp	House Sparrow	+	0	1-25	6	NA	B W
Passeriformes	Regulidae	Regulus	satrapa	gcki	Golden-Crowned Kinglet	-	50-100	0	-89	-1	b W
Passeriformes	Regulidae	Regulus	calendula	rcki	Ruby-Crowned Kinglet	-	50-100	0	-96	0	B w
Passeriformes	Sittidae	Sitta	canadensis	rbnu	Red-Breasted Nuthatch	+	0	600-700	682	2	B W
Passeriformes	Sittidae	Sitta	carolinensis	wbnu	White-Breasted Nuthatch	+	0	700-800	769	444	b W
Passeriformes	Thraupidae	Piranga	ludoviciana	weta	Western Tanager	-	50-100	0	-96	-1	B
Passeriformes	Troglodytidae	Catherpes	mexicanus	cawr	Canyon Wren	0	0	0	0	0	B W
Passeriformes	Troglodytidae	Cistothorus	palustris	mawr	Marsh Wren	0	0	0	0	0	B W
Passeriformes	Troglodytidae	Salpinctes	obsoletus	rowr	Rock Wren	0	0	0	0	0	B
Passeriformes	Troglodytidae	Troglodytes	aedon	howr	House Wren	+	0	700-800	768	489	B
Passeriformes	Turdidae	Sialia	mexicana	webl	Western Bluebird	-	25-50	0	-47	-17	t
Passeriformes	Turdidae	Sialia	currucoides	mobl	Mountain Bluebird	-	700-800	0	-741	-8	B w
Passeriformes	Turdidae	Myadestes	townsendi	toso	Townsend's Solitaire	-	50-100	0	-96	-1	B W
Passeriformes	Turdidae	Cathanrus	guttatus	heth	Hermit Thrush	-	50-100	0	-96	0	B
Passeriformes	Turdidae	Cathanrus	ustulatus	swth	Swainson's Thrush	-	50-100	0	-96	0	B

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Passeriformes	Turdidae	Ixoreus	naevius	vath	Varied Thrush	-	1-25	0	-15	0	t
Passeriformes	Turdidae	Cathanrus	minimus	gcth	Gray-Cheeked Thrush	-	1-25	0	0	0	t
Passeriformes	Turdidae	Cathanrus	fuscenscens	veer	Veery	-	1-25	0	0	0	B
Passeriformes	Turdidae	Turdus	migratorius	amro	American Robin	+	0	600-700	655	5	B W
Passeriformes	Tyrannidae	Empidonax	traillii	wifl	Willow Flycatcher	-	25-50	0	-47	-10	b
Passeriformes	Tyrannidae	Empidonax	oberholseri	dufl	Dusky Flycatcher	-	1-25	0	-16	-5	B
Passeriformes	Tyrannidae	Sayornis	saya	saph	Say's Phoebe	-	1-25	0	-16	-3	B
Passeriformes	Tyrannidae	Tyrannus	verticalis	weki	Western Kingbird	-	1-25	0	-16	-3	B
Passeriformes	Tyrannidae	Empidonax	hammondii	hafl	Hammond's Flycatcher	-	50-100	0	-96	-1	B
Passeriformes	Tyrannidae	Contopus	cooperi	osfl	Olive-Sided Flycatcher	-	50-100	0	-96	-1	b
Passeriformes	Tyrannidae	Empidonax	minimus	lefl	Least Flycatcher	-	1-25	0	0	0	B
Passeriformes	Tyrannidae	Empidonax	occidentalis	cofl	Cordilleran Flycatcher	-	50-100	0	-72	0	g
Passeriformes	Tyrannidae	Tyrannus	tyrannus	eaki	Eastern Kingbird	-	1-25	0	0	0	B
Passeriformes	Tyrannidae	Contopus	sordidulus	wwpe	Western Wood-Pewee	+	0	600-700	644	7	B
Passeriformes	Vireonidae	Vireo	olivaceus	revi	Red-Eyed Vireo	0	0	0	0	0	B
Passeriformes	Vireonidae	Vireo	gilvus	wavi	Warbling Vireo	-	25-50	0	-31	-5	B
Passeriformes	Vireonidae	Vireo	solitarius	sovi	Solitary (Blue-Headed) Vireo	-	50-100	0	-96	-2	b
Pelecaniformes	**Pelecanidae**	**Pelecanus**	**erythtorhynchos**	**awpe**	**American White Pelican**	**0**	**0**	**0**	**0**	**0**	**t**
Pelecaniformes	Phalacrocoracidae	Phalacrocorax	auritus	dcco	Double-Crested Cormorant	-	1-25	0	-13	-4	B
Piciformes	Picidae	Melanerpes	lewis	lewo	Lewis's Woodpecker	0	0	0	0	0	B W
Piciformes	Picidae	Melanerpes	erythrocephalus	rhwo	Red-Headed Woodpecker	0	0	0	0	0	t

Appendix C: (continued)
AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Piciformes	Picidae	Picoides	pubescens	dowo	Downy Woodpecker	-	1-25	0	-15	-8	B W
Piciformes	Picidae	Dryocopus	pileatus	piwo	Pileated Woodpecker	-	50-100	0	-96	-1	g
Piciformes	Picidae	Sphyrapicus	thyroideus	wisa	Williamson's Sapsucker	-	50-100	0	-68	-1	B
Piciformes	Picidae	Picoides	villosus	hawo	Hairy Woodpecker	-	50-100	0	-96	0	B W
Piciformes	Picidae	Picoides	tridactylus	ttwo	Three-Toed Woodpecker	-	50-100	0	-81	0	B W
Piciformes	**Picidae**	**Picoides**	**arcticus**	**bbwo**	**Black-Backed Woodpecker**	**-**	**1-25**	**0**	**-9**	**0**	**b**
Piciformes	Picidae	Sphyrapicus	nuchalis	rnsa	Red-Naped Sapsucker	-	25-50	0	-24	0	B
Piciformes	Picidae	Colaptes	auratus	nofl	Northern Flicker	+	0	600-700	679	5	t W
Podicipediformes	Podicipedidae	Aechmophorus	occidentalis	wegr	Western Grebe	0	0	0	0	0	B
Podicipediformes	Podicipedidae	Podiceps	nigricollis	eagr	Eared Grebe	0	0	0	0	0	b w
Podicipediformes	Podicipedidae	Podilymbus	podiceps	pbgr	Pied-Billed Grebe	-	1-25	0	-9	-4	B w
Podicipediformes	Podicipedidae	Podiceps	auritus	hogr	Horned Grebe	-	1-25	0	-9	-4	t
Podicipediformes	Podicipedidae	Podiceps	grisegena	rngr	Red-Necked Grebe	-	1-25	0	-9	-4	t
Strigiformes	Strigidae	Asio	flammeus	seow	Short-Eared Owl	-	600-700	0	-640	-16	b W
Strigiformes	Strigidae	Otus	kennicottii	wsow	Western Screech Owl	-	1-25	0	-15	-8	g
Strigiformes	Strigidae	Asio	otus	leow	Long-Eared Owl	-	25-50	0	-31	-4	B W
Strigiformes	**Strigidae**	**Otus**	**flammeolus**	**flow**	**Flammulated Owl**	**-**	**50-100**	**0**	**-64**	**-2**	**g**
Strigiformes	Strigidae	Surnia	ulula	nhow	Northern Hawk Owl	-	100-200	0	-128	-1	t w
Strigiformes	Strigidae	Aegolius	acadicus	nswo	Northern Saw-Whet Owl	-	100-200	0	-128	-1	B W
Strigiformes	Strigidae	Glaucidium	gnoma	npow	Northern Pygmy Owl	-	100-200	0	-128	0	b W
Strigiformes	Strigidae	Strix	varia	baow	Barred Owl	-	100-200	0	-124	0	t

Appendix C: (continued)

AVES

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Strigiformes	**Strigidae**	**Strix**	**nebulosa**	**ggow**	**Great Gray Owl**	**-**	**100-200**	**0**	**-122**	**0**	**B W**
Strigiformes	**Strigidae**	**Aegolius**	**funereus**	**boow**	**Boreal Owl**	**-**	**100-200**	**0**	**-116**	**0**	**t**
Strigiformes	Strigidae	Bubo	virginianus	ghow	Great Horned Owl	-	1-25	0	-3	0	B W
Strigiformes	Strigidae	Nyctea	scandiaca	snow	Snowy Owl	+	0	100-200	124	3	t W
Strigiformes	**Strigidae**	**Athene**	**cunicularia**	**buow**	**Burrowing Owl**	**+**	**0**	**100-200**	**118**	**5**	**b**
Strigiformes	Strigidae	Otus	asio	esow	Eastern Screech Owl	+	0	700-800	753	400	b

MAMMALIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Artiodactyla	Antilocapridae	Antilocapra	americana	pron	Pronghorn	-	600-700	0	-637	-17	V
Artiodactyla	Bovidae	Ovis	canadensis	mosh	Mountain (Bighorn) Sheep	0	0	0	0	0	S H
Artiodactyla	Bovidae	Oreamnos	americanus	mogo	Mountain Goat	0	0	0	0	0	V H
Artiodactyla	Cervidae	Odocoileus	hemionus	mude	Mule Deer	-	700-800	0	-772	-3	S H
Artiodactyla	Cervidae	Odocoileus	virginianus	wtde	White-Tailed Deer	-	100-200	0	-129	-1	V
Artiodactyla	Cervidae	Cervus	elaphus	elk	Elk (Wapiti)	-	700-800	0	-758	-2	S H
Artiodactyla	Cervidae	Alces	alces	moos	Moose	-	50-100	0	-92	0	S H
Carnivora	Canidae	Vulpes	vulpes	refo	Red Fox	-	600-700	0	-654	-11	V A
Carnivora	Canidae	Canis	latrans	coyo	Coyote	-	700-800	0	-772	-3	S A
Carnivora	**Canidae**	**Canis**	**lupus**	**grwo**	**Grey Wolf**	**-**	**700-800**	**0**	**-773**	**-2**	**V**

Appendix C: (continued)
MAMMALIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Carnivora	Felidae	Felis	concolor	moli	Mountain Lion	-	100-200	0	-143	0	V
Carnivora	**Felidae**	**Lynx**	**canadensis**	**lynx**	**Lynx**	**-**	**50-100**	**0**	**-78**	**0**	**S**
Carnivora	Felidae	Lynx	rufus	bobc	Bobcat	-	100-200	0	-105	-1	V A
Carnivora	Mustelidae	Taxidea	taxus	abad	American Badger	-	700-800	0	-739	-16	S
Carnivora	Mustelidae	Spilogale	putorius	wssk	Western Spotted Skunk	-	600-700	0	-671	-15	S A
Carnivora	Mustelidae	Mustela	erminea	ermi	Ermine	-	700-800	0	-757	-3	* $
Carnivora	Mustelidae	Mustela	frenata	ltwe	Long-Tailed Weasel	-	700-800	0	-772	-3	S
Carnivora	Mustelidae	Mustela	nivalis	lewe	Least Weasel	-	600-700	0	-685	-17	V
Carnivora	Mustelidae	Mustela	vison	mink	Mink	-	1-25	0	-14	-21	S A
Carnivora	Mustelidae	Mephitus	mephitus	stsk	Striped Skunk	-	700-800	0	-772	-6	S A
Carnivora	**Mustelidae**	**Martes**	**pennanti**	**fish**	**Fisher**	**-**	**50-100**	**0**	**-96**	**0**	**g**
Carnivora	Mustelidae	Martes	americana	amma	American Marten	-	100-200	0	-106	0	S A
Carnivora	Mustelidae	Lutra	canadensis	nrot	Northern River Otter	-	1-25	0	-12	-1	S
Carnivora	**Mustelidae**	**Gulo**	**luscus**	**wolv**	**Wolverine**	**-**	**100-200**	**0**	**-127**	**0**	**S**
Carnivora	Procyonidae	Procyon	lotor	crac	Common Raccoon	-	1-25	0	-16	-3	S
Carnivora	Ursidae	Ursus	americanus	blbe	Black Bear	-	100-200	0	-128	0	V E
Carnivora	**Ursidae**	**Ursus**	**arctos**	**grbe**	**Grizzly Bear**	**-**	**100-200**	**0**	**-143**	**0**	**V E**
Chiroptera	**Vespertilionidae**	**Plecotus**	**townsendii**	**tbeb**	**Townsend's Big-Eared Bat**	**-**	**100-200**	**0**	**-127**	**0**	**S**
Chiroptera	Vespertilionidae	Nycteris	cinerea	hoba	Hoary Bat	+	0	600-700	652	2	S
Chiroptera	**Vespertilionidae**	**Myotis**	**thysanodes**	**frmy**	**Fringed Myotis**	**-**	**700-800**	**0**	**-728**	**-3**	**S**
Chiroptera	Vespertilionidae	Myotis	evotis	lemy	Long-Eared Myotis	-	100-200	0	-143	0	S

Appendix C: (continued)
MAMMALIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Chiroptera	Vespertilionidae	Myotis	lucifugus	lbmy	Little Brown Myotis	+	0	1-25	16	0	S
Chiroptera	Vespertilionidae	Myotis	volans	llmy	Long-Legged Myotis	+	0	600-700	651	2	g
Chiroptera	Vespertilionidae	Myotis	ciliolabrum	wsfm	Western Small-Footed Myotis	+	0	100-200	139	4	?
Chiroptera	Vespertilionidae	Myotis	yumanensis	yumy	Yuma Myotis	+	0	1-25	10	1	S
Chiroptera	Vespertilionidae	Lasionycteris	noctivagans	shba	Silver-Haired Bat	+	0	600-700	652	2	S
Chiroptera	Vespertilionidae	Eptesicus	fuscus	bbba	Big Brown Bat	+	0	1-25	13	0	g
Insectivora	Soricidae	Sorex	cinereus	mash	Masked Shrew	-	600-700	0	-609	-2	S *
Insectivora	Soricidae	Sorex	monticolus	dush	Dusky Shrew	-	1-25	0	-15	0	S $
Insectivora	**Soricidae**	**Sorex**	**preblei**	**prsh**	**Preble's Shrew**	**-**	**1-25**	**0**	**-16**	**-3**	**g**
Insectivora	Soricidae	Sorex	vagrans	vash	Vagrant Shrew	-	100-200	0	-157	-3	g
Insectivora	Soricidae	Sorex	palustris	wash	Water Shrew	0	0	0	0	0	S
Lagomorpha	Leporidae	Sylvilagus	nuttallii	moco	Mountain Cottontail	-	25-50	0	-48	-3	S
Lagomorpha	Leporidae	Lepus	townsendii	wtja	White-Tailed Jackrabbit	-	600-700	0	-654	-12	S
Lagomorpha	Leporidae	Lepus	americanus	snha	Snowshoe Hare	-	50-100	0	-96	0	V $
Lagomorpha	Ochotonidae	Ochotona	princeps	ampi	American Pika	0	0	0	0	0	S *
Rodentia	Castoridae	Castor	canadensis	ambe	American Beaver	-	1-25	0	-15	-1	S A
Rodentia	Cricetidae	Phenacomys	intermedius	hevo	Heather Vole	-	50-100	0	-51	0	V
Rodentia	Cricetidae	Peromyscus	maniculatus	demo	Deer Mouse	-	700-800	0	-728	-2	S * $
Rodentia	Cricetidae	Neotoma	cinerea	btwo	Bushy-Tailed Woodrat	-	25-50	0	-31	0	S $
Rodentia	Cricetidae	Microtus	longicaudus	ltvo	Long-Tailed Vole	-	700-800	0	-772	-3	S
Rodentia	Cricetidae	Microtus	montanus	movo	Montane Vole	-	600-700	0	-684	-5	S *

Appendix C: (continued)
MAMMALIA

ORDER	FAMILY	GENUS	SPECIES	ABBR	COMMON NAME	Trend	AREA (ha) Loss	Gain	Net Δ	% Δ	STAT
Rodentia	Cricetidae	Microtus	pennsylvanicus	mevo	Meadow Vole	-	25-50	0	-32	-6	S
Rodentia	Cricetidae	Microtus	richardsoni	wavo	Water Vole	-	1-25	0	-17	-1	V
Rodentia	Cricetidae	Lemmiscus	curtatus	savo	Sagebrush Vole	-	600-700	0	-654	-16	g
Rodentia	Cricetidae	Clethrionomys	gapperi	srbv	Southern Red-Backed Vole	-	50-100	0	-96	0	S * $
Rodentia	Erethizontidae	Erethizon	dorsatum	copo	Common Porcupine	-	50-100	0	-96	0	S
Rodentia	Geomyidae	Thomomys	talpoides	npgo	Northern Pocket Gopher	-	600-700	0	-682	-6	S * $
Rodentia	Sciuridae	Tamiasciuris	hudsonicus	resq	Red Squirrel	-	50-100	0	-96	0	S * $
Rodentia	Sciuridae	Tamias	amoenus	ypch	Yellow Pine Chipmunk	-	50-100	0	-96	0	S $
Rodentia	**Sciuridae**	**Tamias**	**umbrinus**	**uich**	**Uinta Chipmunk**	**-**	**25-50**	**0**	**-39**	**0**	**g**
Rodentia	Sciuridae	Tamias	minimus	lech	Least Chipmunk	-	1-25	0	-16	-3	S
Rodentia	Sciuridae	Spermophilus	columbianus	cgsq	Columbian Ground Squirrel	-	600-700	0	-661	-12	S
Rodentia	Sciuridae	Spermophilus	richardsonii	rgsq	Richardson's Ground Squirrel	-	600-700	0	-638	-20	S
Rodentia	Sciuridae	Spermophilus	elegans	wgsq	Wyoming Ground Squirrel	-	600-700	0	-683	-18	g
Rodentia	Sciuridae	Spermophilus	armatus	ugsq	Uinta Ground Squirrel	-	25-50	0	-47	-8	S
Rodentia	Sciuridae	Spermophilus	lateralis	gmgs	Golden-Mantled Ground Squirrel	-	100-200	0	-112	-1	S
Rodentia	Sciuridae	Marmota	flaviventris	ybma	Yellow-Bellied Marmot	-	25-50	0	-32	0	S
Rodentia	Sciuridae	Glaucomys	sabrinus	nfsq	Northern Flying Squirrel	-	50-100	0	-96	0	S $
Rodentia	Zapodidae	Zapus	princeps	wjmo	Western Jumping Mouse	-	100-200	0	-147	-2	S * $

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