University of Nevada, Reno

Avian Urban Ecology:
Conservation Planning Opportunities for Reno, NV, USA

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requirements for the degree of Doctor of Philosophy in
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by

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ABSTRACT

The study of urban ecology has grown significantly over the years, resulting in an increased understanding of how human-designed landscapes fit into the larger landscape, and how this impacts local, regional, and global biodiversity. This dissertation explores the relationship between urban birds and the various components that combine to create the urban environment in the cities of Reno and Sparks, Nevada, USA. The first chapter explores the overall pattern of native species diversity, and finds that native species diversity increases as urbanization increases. This pattern appears to be related to the presence of the Truckee River, and its associated riparian habitat. This relationship between riparian habitat and urbanization is explored further in the second chapter, where land use planning is assessed with vegetation as a new way to describe the urban environment (urban form), in order to better describe avian diversity patterns. Urban form, and specifically land use planning, described avian diversity patters better than vegetation alone, suggesting that urban form represents a more robust way to quantify the urban environment. Using the relationships established in the first two chapters, the third chapter models the impacts to avian habitat under three different growth scenarios. This chapter discusses the fact that while avian-centric policies can be an effective tool for conservation, open space plans (which are a critical part of most urban land use plans) can also be effective conservation tools, especially when they are flexible to incorporate locally collected empirical data. A primary tenant of urban ecological research is the identification and implementation of land use plans that protect urban ecological function. This research identifies the opportunities for increased conservation planning in cities, and suggests some specific ways that Reno and Sparks (with generalizations that could help other semi-arid medium sized cities) can increase the implementation of ecologically-based land use plans.

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Introduction

Urban ecosystems are complex environments with many feedback loops that cross socioeconomic and biophysical boundaries (McDonnell and Pickett 1990, Pickett et al. 1997b). Spatially heterogeneous resources, defined by a mix of human and environmental conditions, determine the structure and function of ecosystems in a city (Grove and Burch 1997). Urban habitats are highly varied, often selecting for species with flexible foraging and habitat requirements (Marzluff et al. 2001, Anderies et al. 2007, Devictor et al. 2007, Blair and Johnson 2008), which can lead to novel ecosystems and species interactions. Due to this, ecologists have to approach urban ecology as a fully integrated human-environment system (Pickett et al. 1997a).

Urban ecological research has greatly benefited from the establishment of two urban National Science Foundation Long-Term Ecological Research sites in Baltimore, Maryland and Phoenix, Arizona in the late 1990s. Prior to this, most ecologists ignored urban environments because they were seen as homogenous human landscapes with little ecological value (Odum 1971, Grimm et al. 2008). Research from both of these sites have demonstrated that urban environments provide an opportunity to study how species adapt to rapid environmental change (Alberti et al. 2003, Hobbs et al. 2006), provide a platform for investigating island biogeography, intermediate disturbance theory and other landscape ecological principles (Breuste et al. 2008), and can help determine how coupled human-natural systems have synchronously developed (Araujo 2003, Luck 2007, Luck 2010).

Likewise, current research has shown the conservation value of some urban habitats for regional biodiversity. Remnant and artificial riparian habitat located within urbanization is one example of highly desirable habitat for regional conservation (Terman 1997, Merola-Zwartjes and DeLong 2005, Atchison and Rodewald 2006, Rodewald and Bakermans 2006, Hodgkison et al. 2007, Oneal and Rotenberry 2009). Likewise, the high level of heterogeneity in structure and resources available along an urban-rural gradient can provide a variety of habitats within a short distance, creating additional habitat niches for species of concern (Blair 1996, Clergeau et al. 1998, Blair 1999, Chapman and Reich 2007). Furthermore, the need to identify conservation priorities within urban environments is increasingly important as urbanization continues expanding into biodiversity hotspots, especially as urbanization is often cited as the major driver of threatened or endangered species (Miller and Hobbs 2002).

One of the key objectives in urban ecological research is to identify ways to reduce the negative impact urbanization has on biodiversity, yet most urban ecology studies fail to do this within a planning framework (McIntyre and Knowles-Yanez 2000). More commonly, studies identify the importance of native vegetation, patch size, or other habitat-specific variables (Loss et al. 2009). While this approach is appropriate for natural systems where land managers can focus on specific habitat characteristics, planners need land use objectives that can be implemented within land use policies and plans (Gordon et al. 2009). Land use planners lack the ability to actively manage habitat in urban environments; that responsibility falls primarily on individual land owners. However, land use planners can determine the juxtaposition and proximity of land uses to other managed areas. This requires ecologists to think differently and clearly identifies the need for further integration of urban ecology and land use planning.

The objective of this research was to determine the features of the urban environment that are driving avian richness, and how this knowledge can be translated into land use policies that promote bird diversity now and in the future for the Truckee Meadows region of Nevada, USA. The objective of the first chapter was to establish the pattern of bird diversity in the urban landscape. This was done using point-count observations of bird species across Reno, and using multivariate analysis to assess the importance of local and landscape variables in shaping bird diversity. This chapter provides the foundation for species richness and abundance patterns in the larger urban environment, and inspired the research in the second chapter. The objective of the second chapter was to examine the role of urban form, the combination of land use planning and vegetation variables, in predicting avian diversity. Avian response to urban form is assessed to understand the viability of urban riparian habitat in Reno and Sparks, and to identify specific planning concepts that can be promoted for avian diversity. The third chapter integrates the results from the first two chapters by developing policies to promote avian conservation. These policies are modeled using scenario analysis to determine the effectiveness of an open space plan in protecting important avian habitat, and identify habitat that might be lost if no conservation policies are enacted.

The cities of Reno and Sparks, located within the Truckee Meadows, Nevada, are chosen for this research because they represent a medium-sized urban environment with historically rapid growth (28% per decade from 1980-present), and the potential to double in growth again in the next 40 years, despite current and historical population fluctuations (Hardcastle 2010a, b). Most urban ecological research has focused on large cities (> 1 million residents) and have found an overall reduction in species richness, increase in abundance, and loss of specialist species (Chace and Walsh 2006, McKinney 2006, Hamer and McDonnell 2008). While studying the effects of urbanization at this scale is important, smaller cities may have a reduced urban effect (Baldwin et al. 2009, Garaffa et al. 2009, Smallbone et al. 2011). With approximately 400,000 residents, the Truckee Meadows represents a smaller urban environment that is analogous in population and development history to many other semi-arid cities through the western U.S. and the world. Studying urban ecology in a city prior to its build-out provides an opportunity to test urban biodiversity relationships as they develop. Furthermore, studying a growing region can help identify important habitat reserves, providing an opportunity to test the effectiveness of urban reserves, and an opportunity to examine urban conservation policy.

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Chapter 1: Avian response to urbanization in the arid riparian context of Reno, USA

E. Jamie Trammell, Peter J. Weisberg, Scott Bassett

Abstract

The difference between the urban and non-urban environment in arid landscapes can be quite distinct because of the large water and nutrient (along with many other) subsidies provided by human development. With these subsidies comes the potential to increase vertical structure and vegetation diversity over the natural landscape, creating artificial habitats. We assessed how birds were responding to urbanization in Reno, Nevada, USA (pop ~200,000), located in a semi-arid, “cold desert” climate. Despite a heavily developed core, we found that native richness increased as urbanization increased. Our analysis suggests that this pattern is driven by the Truckee River that flows through the city. Remnant riparian patches could combine with urban landscaping to effectively extend riparian habitat into the city. The role of urban riparian habitats for native bird conservation needs to be assessed as urbanization continues in arid regions.

Keyword: CART, landscape context, NMS, Random Forests, recursive partitioning, urban planning

Introduction

Urban ecosystems are unique combinations of socioeconomic factors, land use patterns and characteristics of the surrounding landscape. The impacts of urbanization on native avifauna have been documented in a wide variety of habitats, ranging from the Sonoran Desert (Rosenberg et al. 1987, Green and Baker 2003) to Mediterranean climates (Luther et al. 2008, Shwartz et al. 2008) to tropical regions (Hodgson et al. 2007, Acevedo and Aide 2008, Suarez-Rubio and Thomlinson 2009) to prairie systems (Atchison and Rodewald 2006, Blair and Johnson 2008, Pennington et al. 2008). While some reviews have made the case that urbanization generally results in reduced native and specialist species (Chace and Walsh 2006), there is increasing evidence that the impact urban development has on avian diversity depends upon the landscape context (Rosenberg et al. 1987, Saab 1999, Watson et al. 2005), surrounding human population (Fuller et al. 2009), scale of examination (Araujo 2003, Pautasso 2007, Hugo and van Rensburg 2008) and gradients present (Blair 1996, Blair 2004).

Loss of habitat is often the primary cause for reduced bird diversity in urban environments (Marzluff et al. 2001). In many urban environments, loss of vegetation structure leads to limited nesting and foraging habitat (Er et al. 2005, Shochat et al. 2006, Schlesinger et al. 2008), although habitat heterogeneity (Kennedy et al. 2010) and reduced native predators (Ryder et al. 2010) may compensate for this effect. However, in arid and semi-arid regions, urban environments can experience increased vegetation abundance and structure (Emlen 1974, Merola-Zwartjes and DeLong 2005, Rodriguez-Estrella 2007) and higher net primary productivity (Imhoff et al. 2004, Buyantuyev and Wu 2009). Studies that have assessed the response of birds to urbanization in arid environments have shown that presence of native vegetation (Germaine et al. 1998) and maintenance of natural riparian areas (Green and Baker 2003) help maintain high native avifauna richness.

The importance of riparian habitat for bird diversity in arid regions has been established both in natural landscapes (Saab 1999) and in urban landscapes (Oneal and Rotenberry 2009). While urbanization near natural riparian habitat can reduce native bird diversity (Rottenborn 1999, Luther et al. 2008), urban riparian habitat, although altered, may still be important for regional biota (Seymour and Simmons 2008, Schneider and Griesser 2009). This close interface between riparian habitat and urbanization in an arid landscape has the potential to lead to reduced biodiversity, but can also lead to opportunities for conservation (Rosenberg et al. 1987).

The objective of this research is to determine how native bird abundance and distribution vary with urbanization in a semi-arid landscape. Specifically, we are interested in how the presence of a perennial river at the core of an urban environment influences avian species richness, abundance, and community composition. We use multivariate analysis to explore the relationship of riparian habitat and urbanization on native avifauna. In water-limited environments experiencing urban development, it is important to understand the ecological role of rivers and associated riparian habitats to better inform ecologically-based urban planning, especially where riparian areas are utilized by both wildlife and humans (Green and Baker 2003, Urban et al. 2006, Bark et al. 2009).

Methods

Study Area

Our Reno, Nevada study area is located on the western edge of the Great Basin at the foothills of the Sierra Nevada Mountains in the western United States (39° 31’ N, 119° 48’ W). Vegetation consists primarily of sagebrush steppe with cottonwood riparian woodland along the Truckee River. Temperatures are typical of a higher altitude (1,600m), semi-arid desert with a mean daily temperature of 10.7° C (NOAA 2010). Average annual precipitation is 184 mm, most of it falling in the form of snow in the winter months (WRCC). The Truckee River is fed almost entirely by snowmelt from the Sierra Nevada Mountains, and serves as the permanent water source for the metropolitan area, as it bisects Reno and adjoining Sparks, NV. Although Truckee River flows may become significantly reduced in the late summer, base flow for most of the year is approximately 8.5 cubic meters per second (USGS 2010).

The city of Reno covers approximately 190 km^2 in the Truckee Meadows with an estimated population of 199,000 in 2004 when the field work was completed (Hardcastle 2010). Like many arid cities in the western U.S., much of the population growth has occurred in the previous 40 years, making most of the urban environment relatively young. Additionally, Reno is still considered a smaller city in the western U.S., but has the potential to double in population over the next 40 years (TMWA 2010), making this an ideal place to study avian relationships in a smaller urban environment prior to its build out (Grimm et al. 2000, Garaffa et al. 2009). The relationship between Reno and the Truckee River is similar to many other semi-arid cities that have developed along a permanent water supply, making Reno a good location to study the dynamics of urban avian ecology in a smaller, semi-arid urbanized landscape.

Bird Survey Point Counts

As an initial step in identifying potential habitats within the Reno study area, remnant habitat patches larger than 0.5 ha were digitized into a GIS using 3-m resolution, 24-bit color orthophotographs acquired from the National Agriculture Imagery Program (NAIP) in 2002. Images were segmented into polygons of maximum spectral and textural homogeneity using eCognition image processing software (version 4.0, Definiens Imaging, München, Germany). The software segments images into self-similar polygons based on user-defined scale, color, and shape parameters to highlight vegetation characteristics. The resulting 4,355 polygons for all areas in and within 5 km of the urban boundary were manually photo-interpreted into one of the four vegetation types: coniferous forest, deciduous forest, riparian and upland/range. Vegetation categories were ground-truthed, but were used only to stratify point count locations. Although habitat type can be a good predictor of bird diversity (Heikkinen et al. 2004), we used continuous habitat and vegetation data to better describe the influences of urbanization (Gustafson 1998). Seventy-three point count locations, randomly located in the remnant habitat patches, were surveyed twice during the breeding season of 2004 (May-July), documenting birds visually and by call. Point counts were spaced at least 230m apart to minimize the likelihood of double counting. Fifty meter radius point counts followed methodologies described by Ralph et al (1993), consisting of 8 minute observations after a 5 minute calm down period. Bird locations within the 50m radius were recorded in relation to the observer using estimated distances. All point counts were completed within three hours after sunrise and counted only birds actively using the habitat (i.e. no flyovers were analyzed). Only species with > 5 observations at > 3 sites were included in the community analysis, while all birds were included in the richness and abundance analysis.

Environmental Variables

There has been substantial debate over the relative importance of local (Luther et al. 2008, Oneal and Rotenberry 2009) vs. landscape variables (Suarez-Rubio and Thomlinson 2009, Urbanova 2009, Hedblom and Soderstrom 2010) for influencing avian distribution. Therefore, local and landscape variables describing anthropogenic and natural environmental influences were collected for each point count location (Table 1). Most local variables were collected in the field through vegetation surveys and observations of disturbances and focused on vegetation structure (Luther et al. 2008) and proximal anthropogenic disturbances (Oneal and Rotenberry 2009). Tree layer and disturbance information was collected within 50m, while shrub and herbaceous layers were sampled within a 20m radius. Vegetation cover was visually estimated and calibrated by GRS densitometers, and tree density was tallied by diameter class. Landscape variables were derived in ArcGIS 9.1 (ESRI, Redlands, California) using multiple spatial analysis techniques with FragStats 3.3 software (McGarigal et al. 2002). To assess the scale dependence of avian response to urbanization (Oneal and Rotenberry 2009), building and pavement cover within 100, 200, 300, 400, and 500 m circular buffers around the point counts were photo-interpreted from 1-m resolution, true-color NAIP imagery. All cover information was lumped into 10% bins (i.e. 1 = > 0 to < 10, 2 = 10-20, etc). Distances from roads, arterials and highways, as well as road density were generated in ArcGIS using a detailed road coverage available from Washoe County GIS (http://www.co.washoe.nv.us/gis/datawarehouse.htm). Road density was calculated using the line density function in ArcGIS with a cell size of 10m and search radius of 1,000m to ensure accurate density estimation. Distance from urban-rural boundary was generated for each point count location from the official City of Reno growth boundary, available at the Washoe County GIS site. FragStats was used to calculate patch shape and area to represent possible edge effects and describe the core area (Mason et al. 2007) as well as proximity and nearest neighbor index to represent isolation/connectivity effects (Fernandez-Juricic and Jokimaki 2001, Nichol et al. 2010) within a 10km radius of each point count location. The 10km search radius was chosen in order to incorporate all patches in the landscape, although patches very far away receive very little weight (McGarigal et al. 2002).

Species Patterns

Species richness and relative species abundance patterns were modeled as Random Forests-derived classification and regression trees in the program R using recursive partitioning. Classification and regression tree analysis (CART) is a non-parametric method that creates a decision tree by splitting data successively into increasingly homogeneous groups (nodes). The CART approach was chosen for its simplicity in interpretation and incorporation into a GIS, and its ability to represent hierarchical relationships and ecological thresholds. The ability to map biologically relevant thresholds in urban development is particularly important for regional planners, making CART a useful and intuitive method for this type of analysis (Marmion et al.

2009). Recursive partitioning (RPART package in R) (Shannon et al. 2001) was used to minimize over-fitting. RPART allows v-fold cross-validation, which is useful for smaller datasets by deriving optimally sized classification trees based on validation (De'ath and Fabricius 2000). This is done by dividing the dataset into 10 random subsets and excluding them one at a time from tree construction. The final tree is selected based on the tree with the smallest estimated error rate through that process. Additionally, because CART modeling is sensitive to the order and number of variables used as predictors, Random Forest models (Breiman 2001, Peters et al. 2007) were used to identify the top environmental and urban variables that best explained the richness patterns. Random Forest works as a learning technique where bootstrap samples are used to construct many (in this case 500) classification or regression trees. For each tree, a random subset of variables is used, and the resulting tree is tested against data not used in the construction of the tree (called “out-of-bag” data). Random Forests then ranks the variables that are most often chosen to split the data. We used the top five variables identified by the Random Forests algorithm to develop RPART regression trees. Classification accuracy, number of observations per node, and residual mean difference are reported. Species richness was mapped in a GIS using the identified predictor thresholds from RPART trees.

Environmental Gradient Analysis

To better understand the underlying environmental gradients influencing native species distributions, nonmetric multidimensional scaling (NMS) ordinations in the software package PC-ORD 5.0 (McCune and Grace 2002) were developed (O'Dea and Whittaker 2007, Hudson and Bird 2009, Vallejo et al. 2009). NMS is an indirect ordination method that has the least number of assumptions about the patterns of species distribution along environmental gradients. Euclidean distance was used to measure the multidimensional space between species. Because NMS requires the number of axes to be determined *a priori*, the first ordination was run using a 6-axis solution with a stability criterion of 0.00001, and 250 permutations each with real and randomized data. The final solution included the minimum number of axes that provided the lowest overall stress and instability. Corresponding environmental variables with a R^2 greater than 0.2 (McCune and Grace 2002) were plotted as vectors to help interpret the environmental gradients responsible for shaping species distributions. Both native and exotic species were included in this analysis in order to better understand potential avian assemblages.

Results

Bird Observations

A total of 56 species of birds were used for the diversity analyses, while only 35 were abundant enough to be used in the community-level ordination analyses (Table 2). All but three species counted were considered native. The Mourning Dove (*Zenaida macroura*) was the most abundant bird observed with 246 observations, while the House Finch (*Carpodacus mexicanus*) had 202 observations and Cliff Swallow (*Petrochelidon pyrrhonota*) had 188 observations. Total abundance was 2,788 individuals, with 2,149 of those birds being native species.

Native Richness and Abundance

Classification and regression tree results identified several key environmental influences that best describe native bird richness and abundance patterns. From Random Forests modeling, the top variables (in order of importance) for native species richness were: the distance from the Truckee River (-), patch area (-), mean height of shrubs (+), distance to nearest water (+), and distance from urban-rural boundary (+). The top variables for abundance (in order of importance) were: road density within a 500m radius (+), patch area (-), distance to nearest road (-), distance from urban-rural boundary (+), and the presence/absence of trash (+). The most parsimonious CART model for native species richness only included distance from the Truckee River and patch area, while the final CART model for native bird abundance incorporated three variables: distance to nearest road, distance to urban-rural boundary and patch area (Figure 1).

Native bird richness appears to be influenced primarily by distance to the Truckee River (Figure 1a). According to the regression tree, the influence of the Truckee River can be visualized at three different levels. First there is a split at distances far from the river (3,400m), potentially accounting for the native bird species that are associated with shrub-dominated, rangeland habitats. Another split at 1,600m appears to highlight native generalist species. The final split occurs at 520m from the river, representing the highest richness areas, and potentially riparian-specific species. Thus, this model shows decreased richness along a distance gradient from the Truckee River out into the rangeland (Figure 2).

Native bird abundance appears to be influenced primarily by human-created environmental variables, in contrast to natural environmental variables for richness. The most influential predictor of native abundance is distance from nearest road, with closer distances yielding higher abundances (Figure 1b). At distances from roads greater than 250m, there are also relatively high abundances, especially in suburban habitats near the urban-rural boundary, both within and outside the urban environment. Smaller patches that are isolated from other habitats show high abundances. Larger habitat patches (greater than 4.5 hectares) located close to roads are also predicted to have high native abundance.

Environmental Gradients

NMS ordination results showed three potentially important gradients underlying avian assemblage structure in the greater Reno area, explaining a total of 78% of the overall variance (overall stress = 18.74; orthogonality = 100%). A single axis (Axis 2) explained 43% of the variance and described a gradient from locations that are deeply within the city limits, have a high road density, and are close to the Truckee River, to those that are far from the city limit, roads, or the Truckee River (Figure 3a & b). Bird species with low scores on this axis included rangeland species such as Rock Wren (*Salpinctes obsoletus*), Western Meadowlark (*Sturnella neglecta*), and Black-billed Magpie (*Pica hudsonia*). Species with highest scores included riparian species such as Black-headed Grosbeak (*Pheucticus melanocephalus*), Downy Woodpecker (*Picoides pubescens*), Brewer's Blackbird (*Euphagus cyanocephalus*), Tree Swallow (*Tachycineta bicolor*), Black-chinned Hummingbird (*Archilochus alexandri*), and Bewick's Wren (*Thryomanes bewickii*) (Rich 2002). This axis therefore describes a gradient of riparian influence that has a strong positive association with the urbanization gradient.

Axis 3 of the NMS ordination explained slightly over 20% of the overall variance and described a gradient of urban influence distinct from riparian effects (Figure 3b). Environmental variables with strong correlations with this axis included building cover (positive correlation) and distance from arterial roads (negative correlation). Species with highest Axis 3 scores (i.e. "urban species") included Rock Pigeon (*Columba livia*), Red-winged Blackbird (*Agelaius phoeniceus*), European Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), American Crow (*Corvus brachyrhynchos*), Black-chinned Hummingbird (*Archilochus alexandri*), and Northern Mockingbird (*Mimus polyglottos*). Species with lowest Axis 3 scores (i.e. potential "wildland" species) included Warbling Vireo (*Vireo gilvus*), Western Wood Pewee (*Contopus sordidulus*), and Black-headed Grosbeak (*Pheucticus melanocephalus*). From this axis we can see some separation of the effects of urbanization and the effect of the Truckee River on native species.

NMS Axis 1 explained 14% of the overall variance, but was not significantly correlated with any of the measured environmental predictor variables (Figure 3a). Species with highest Axis 1 scores included both rangeland and wetland species that share a proclivity for open areas, marshy areas, or sparse forest with large openings (e.g. Cliff Swallow, Red-winged Blackbird, Song Sparrow, *Empidonax* Flycatchers, Black-billed Magpie, and Northern Mockingbird). Species that require dense forest or are more common in higher-elevation coniferous forests in the foothills surrounding the urban area had lower scores (e.g. Mountain Chickadee, Western Tanager, and Common Crow). Axis 1 likely describes a gradient of forest vegetation that was not well captured by the measured tree density variables.

The combination of Axes 2 and 3 most clearly describes avian assemblage structure in Reno and corroborates the key influences on avian species richness identified in the CART analysis (Figure 3b). Western Meadowlark and Rock Wren stand out as indicator species of relatively undisturbed rangelands (Figs. 1a, 3b). Species of deciduous riparian forests that are less disturbed had species score centroids that correlate to habitats further from arterial roads, but close to the Truckee River (e.g. Warbling Vireo, Black-headed Grosbeak, Western Wood Pewee, Tree Swallow, and Steller's Jay). Species of urbanized riparian environments had species score centroids that placed them in habitats closer to roads and in areas with higher building and pavement cover, but still close to the Truckee River (e.g. Black-Chinned Hummingbird, Brewer's Blackbird, Red-winged Blackbird, Downy Woodpecker, and Bewick's Wren). Generalist species, including California Quail, Black-billed Magpie, House Finch, and American Robin, had low scores in both ordination axes. Predictor variables most influential for describing effects of urbanization on avian assemblage structure appear to be building cover, pavement cover, distance from nearest road, distance from the nearest arterial road, and distance from the urban boundary (Figure 3).

Discussion

Native bird response to urbanization in an arid landscape

The Truckee River strongly influences spatial patterns of native richness in Reno, resulting in greater native bird richness within the most developed portion of Reno. While there are many studies that have found increasing species richness with increasing urbanization at regional or global scales (Araujo 2003, Luck 2007, Hugo and van Rensburg 2008, Moreno-Rueda and

Pizarro 2009, Chiari et al. 2010, Luck 2010), this study provides evidence of species richness increasing with human development at the city-wide scale. Similar to other studies, it appears that this pattern is strongly influenced by riparian habitat that has been maintained in an urban environment (Rosenberg et al. 1987, Miller et al. 2003, Rodewald and Bakermans 2006, Fletcher and Hutto 2008, Hugo and van Rensburg 2008, Oneal and Rotenberry 2009, Hedblom and Soderstrom 2010). As with many semi-arid cities, urbanization is highest along portions of the Truckee River (Patten and Rotenberry 1998). In this study, native richness was highest immediately near the Truckee River, and at distances from 1,600m to 3,400m from the river. The increased richness at intermediate distances supports the conclusions of many of the urban-rural gradient studies (Blair 1996, Chapman and Reich 2007, Blair and Johnson 2008) as suburban development dominates the land use starting at 1km from the Truckee River extending to the urban boundary. The increase in irrigation, vegetation structure, parks (Shwartz et al. 2008) and gardens (Doody et al. 2010) that accompany suburban development could be extending the riparian habitat into the city, possibly explaining the higher species richness at 1,600 to 3,400m from the river. The increased richness immediately around the Truckee River, despite the intense urbanization present, suggests that remnant riparian habitat may reduce the negative effects of local urbanization on bird species richness in semi-arid habitats. Although we were unable to disentangle the covarying influences of increasing urbanization and presence of riparian habitat, it appears that riparian habitat is still an important factor in determining avian richness, even in urban landscapes (Oneal and Rotenberry 2009).

Our findings corroborate previous research that calls for maintenance of riparian habitat for avian conservation (Rottenborn 1999, Saab 1999, Green and Baker 2003, Palmer and Bennett 2006, Rodewald and Bakermans 2006, Luther et al. 2008). However, our results also identify certain bird species that may not respond so favorably to urbanization (most rangeland species, and a few disturbance-intolerant, riparian species). Additional consideration of larger-scale (gamma) diversity is necessary before concluding that semi-arid urban environments can play an important role in regional avian conservation. The possibility that remnant riparian patches act as sinks for regional avian diversity also needs to be further explored (Leston and Rodewald 2006), especially when considering the increased abundance observed near roads in this analysis.

Planning Implications

Improved urban planning based on locally focused environmental research is critical for reducing the negative impacts of urbanization on biodiversity (Grimm et al. 2000). The importance of urban green space and parks, specifically those focused around urban rivers, has been established on environmental (Atchison and Rodewald 2006, Pennington et al. 2008) as well as socioeconomic (Acharya and Bennett 2001, Kline 2006, Chen and Jim 2008) grounds. This research supports the call for better protection of river habitats and riparian corridors in semi-arid urban environments to promote bird conservation. Landscape features that promote native bird richness, such as distance from the Truckee River, best describe the observed native species richness patterns, suggesting that planners should focus on designating more parks and open space close to the Truckee River to protect remnant riparian habitat The observation that variables like road density and the presence of people did not negatively impact overall native richness suggests there may be a role for urban habitats in native bird conservation, though more research into survival and fitness of birds near these land uses is required before land use policies should be adopted.

Future Research

Our Reno study area is fortunate in that riparian patches along the Truckee River have been protected as parks and other open space, even as the river flows through densely urbanized areas. Given the importance of rivers and their associated riparian forests to biota in arid environments, it would be useful to quantify how much and where urban riparian habitat exists. Likewise, research into the potential of suburban development in mimicking riparian habitat by creating water-rich, structurally diverse habitats will help in riparian bird conservation (Blair and Johnson 2008).

The value of riparian areas in Reno has been recognized within the context of flood control, but the value as habitat for native fauna has yet to be quantified. Further research into how biodiversity varies along urban rivers, especially in varying levels of development and with different surrounding land use, is critical for improved management of urban riparian systems (Smith and Wachob 2006). Likewise, research into the potential of urban landscape features to extend the distribution and connectivity of riparian habitat is needed, especially given the ability of planners to encourage tree plantings and zoning for various habitat variables (i.e. reduced road density or pavement cover).

Conclusion

The difference between the urban and non-urban environment in arid landscapes is distinct because of the large water subsidy provided by human development. This research has highlighted the importance of understanding the landscape context of a city in determining the potential response of native bird species to urbanization (Fletcher and Hutto 2008, Luther et al. 2008). The strong effect of the Truckee River on avian richness patterns highlights the importance of riparian habitat in arid urban environments. Local ecological research is needed to provide regional planners with the best available data for designing urban landscapes, emphasizing the ecology of cities and not just ecology in cities (Grimm et al. 2000, McDonnell and Hahs 2008). Ecologists, or ecologically trained planners, are best poised to understand the functional difference between the natural and urban environments, especially in arid environments where the difference is more than just a difference in land use, but a difference in water availability, ecological productivity and heterogeneity of habitat structure.

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Local variables	**Description**
Distance to water	Distance to nearest water (m), measured from a shapefile of water bodies using GIS
Distance to trail	Distance to nearest visible undeveloped or developed trail (m), measured from a shapefile using GIS
Tree density	Overall tree density/ha, measured in the field
Tree density (5-25cm DBH)	Smaller tree density/ha, measured in the field
Tree density > 25cm DBH	Larger tree density/ha, measured in the field
Shrub cover	Percent aerial cover from shrubs, measured in the field
Perennial grass cover	Percent aerial cover from perennial grasses, measured in the field
Annual grass cover	Percent aerial cover from annual grasses, measured in the field
Forb cover	Percent aerial cover from forbs, measured in the field
Vegetation Diversity	Index: 1 for just trees up to 5 for all vegetation classes (trees, shrubs, perennial grass, annual grass and forbs) present
Pavement cover	Percent aerial cover from pavement, measured using aerial photographs in GIS
Trash cover	Percent aerial cover from trash, measured in the field
Disturbance Index	Index: 1 for largely undisturbed to 4 for highly disturbed, measured in the field
People	Presence (1) or absence (0)
Dogs	Presence (1) or absence (0)
Landscape variables	**Description**
Distance from arterial road	Distance from nearest arterial road (m)
Distance from highway	Distance from nearest highway (m)
Distance from road	Distance from nearest road of any size (m)
Distance from Truckee	Distance from the Truckee River (m)
Distance from urban-rural boundary	Measured in meters. Negative values indicate distances outside of urban environment, positive indicate distance within urban environment. Large positive distances represent the habitats furthest within the urban boundary.
Road density	Density (km/ha) of roads within 100m, 200m, 300m, 400m and 500m radii
Building cover	Percent cover within 100m, 200m, 300m, 400m and 500m radii

Pavement cover	Percent cover in 100m, 200m, 300m, 400m and 500m radii
Patch area	Continuous patch (ha)
Shape index	Calculated from FragStats using 10km radius
Proximity index	Proximity to similar habitats, calculated from FragStats using 10km radius
Nearest neighbor index	Distance to nearest habitat, calculated from FragStats using 10km radius

Table 1: Description of environmental variables used to analyze bird distributions in Reno, NV. Local variables were primarily measured on site, while landscape variables were all generated with ArcGIS 9.1 (ESRI, Redlands, California) and FragStats 3.3 (McGarigal et al., 2002).

	Common Name	Scientific Name
	American Goldfinch	*Carduelis tristis*
+	American Kestrel	*Falco sparverius*
	American Robin	***Turdus migratorius***
*	Band-tailed Pigeon	*Patagioenas fasciata*
	Barn Swallow	***Hirundo rustica***
	Bewick's Wren	***Thryomanes bewickii***
	Black-billed Magpie	***Pica hudsonia***
	Black-chinned Hummingbird	***Archilochus alexandri***
	Black-headed Grosbeak	***Pheucticus melanocephalus***
	Black-throated Sparrow	*Amphispiza bilineata*
	Blue-gray Gnatcatcher	*Polioptila caerulea*
	Brewer's Blackbird	***Euphagus cyanocephalus***
	Brown-headed Cowbird	***Molothrus ater***
	Bullock's Oriole	***Icterus bullockii***
	Bushtit	*Psaltriparus minimus*
*	California Gull	*Larus californicus*
	California Quail	***Callipepla californica***
+	Canada Goose	*Branta canadensis*
	Cliff Swallow	***Petrochelidon pyrrhonota***
	Common Crow	***Corvus brachyrhynchos***
+	Common Merganser	*Mergus merganser*
	Common Nighthawk	*Chordeiles minor*
+	Cooper's Hawk	*Accipiter cooperii*
+	Double Crested Cormorant	*Phalacrocorax auritus*
	Downy Woodpecker	***Picoides pubescens***
	Empidonax spp	***Empidonax* spp.**
	European Starling	***Sturnus vulgaris***
*	Golden Eagle	*Aquila chrysaetos*
	Gray Flycatcher	*Empidonax wrightii*
+	Great Horned Owl	*Bubo virginianus*
	Hairy Woodpecker	*Picoides villosus*
	Horned Lark	*Eremophila alpestris*
	House Finch	***Carpodacus mexicanus***
	House Sparrow	***Passer domesticus***
	House Wren	***Troglodytes aedon***
+	Killdeer	*Charadrius vociferus*
	Lark Sparrow	*Chondestes grammacus*
	Lesser Goldfinch	***Carduelis psaltria***
	Lewis's Woodpecker	*Melanerpes lewis*
+	Mallard	*Anas platyrhynchos*

	Mountain Chickadee	***Poecile gambeli***
	Mourning Dove	***Zenaida macroura***
	Northern Flicker	***Colaptes auratus***
	Northern Mockingbird	***Mimus polyglottos***
	Northern Raven	*Corvus corax*
	Northern Rough-winged Swallow	*Stelgidopteryx serripennis*
	Orange-crowned Warbler	*Vermivora celata*
*	Prairie Falcon	*Falco mexicanus*
	Pygmy Nuthatch	*Sitta pygmaea*
	Red-breasted Sapsucker	*Sphyrapicus ruber*
+	Red-tailed Hawk	*Buteo jamaicensis*
	Red-winged Blackbird	***Agelaius phoeniceus***
	Rock Pigeon	***Columba livia***
	Rock Wren	***Salpinctes obsoletus***
	Rufous Hummingbird	*Selasphorus rufus*
	Say's Phoebe	*Sayornis say*
	Song Sparrow	***Melospiza melodia***
+	Spotted Sandpiper	*Actitis macularia*
	Spotted Towhee	***Pipilo maculatus***
	Steller's Jay	***Cyanocitta stelleri***
	Tree Swallow	***Tachycineta bicolor***
+	Turkey Vulture	*Cathartes aura*
	Vesper Sparrow	*Pooecetes gramineus*
	Violet-green Swallow	*Tachycineta thalassina*
	Warbling Vireo	***Vireo gilvus***
	Western Bluebird	*Sialia mexicana*
	Western Kingbird	*Tyrannus verticalis*
	Western Meadowlark	***Sturnella neglecta***
	Western Scrub Jay	***Aphelocoma californica***
	Western Tanager	***Piranga ludoviciana***
	Western Wood Pewee	***Contopus sordidulus***
+	White-faced Ibis	*Plegadis chihi*
	Wilson's Warbler	*Wilsonia pusilla*
	Yellow Warbler	*Dendroica petechia*

Table 2: Total species list for all surveys collected in and around Reno in the summer of 2004, along with mean and standard deviation of their abundance. Species marked with * were observed only as flyovers, while + indicates non-songbirds that were excluded from all analyses. Bold fonts mark species seen at least 5 different times in at least 3 different point locations.

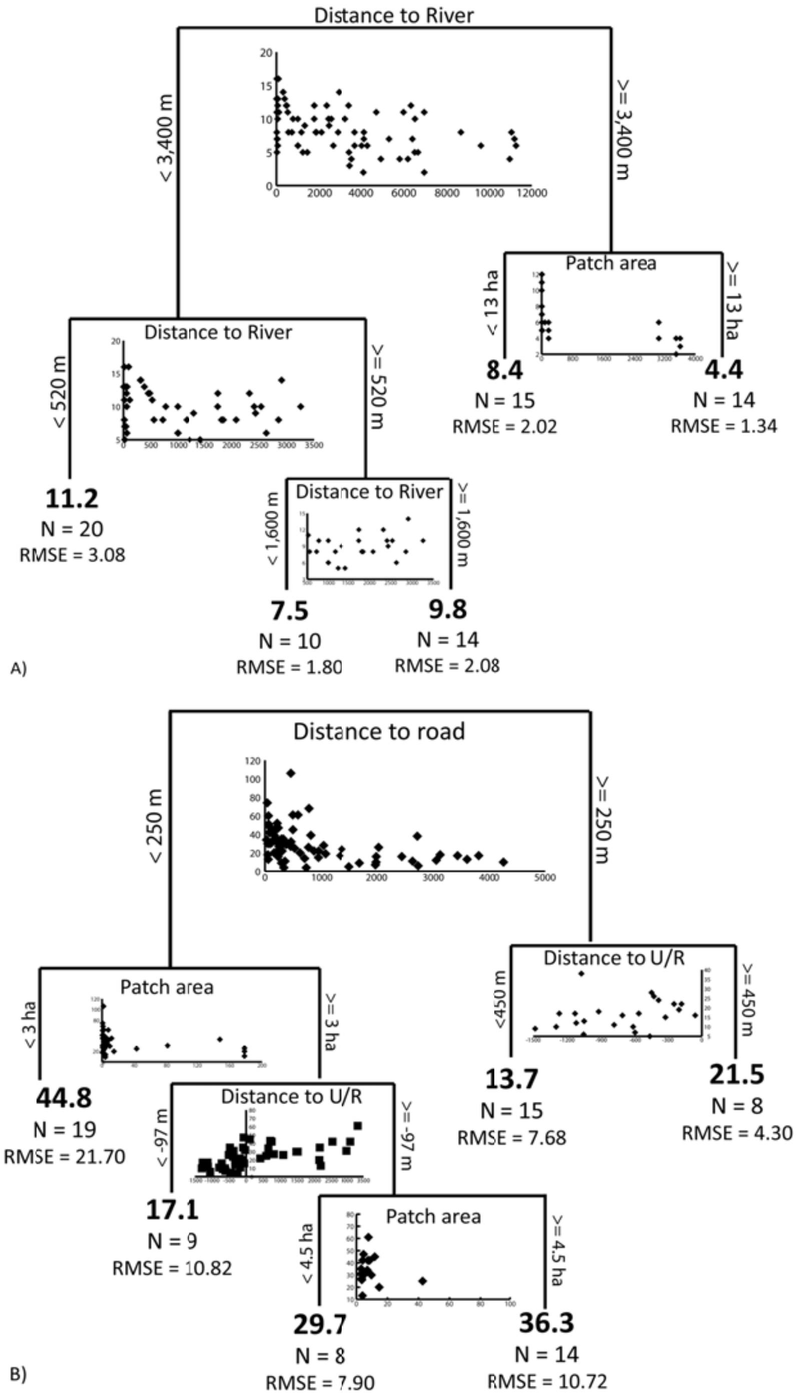

Figure 1: CART models for native bird richness (a) and abundance (b) in urban Reno, NV. Each of the splits are labeled with the value of the variable used to make the split. Scatterplots show richness (a) and abundance (b) against the variables used in the splits. The mean response values are shown at the terminal nodes (in bold), along with the number of observations that follow the criteria and the root mean squared error. Native bird richness is highest in habitats close to the Truckee River, while native bird abundance is highest in smaller (patch area) habitats with lower road density in town. 41% of the variance is explained by the native bird richness tree, while 55% of the variance is explained by the native bird abundance tree.

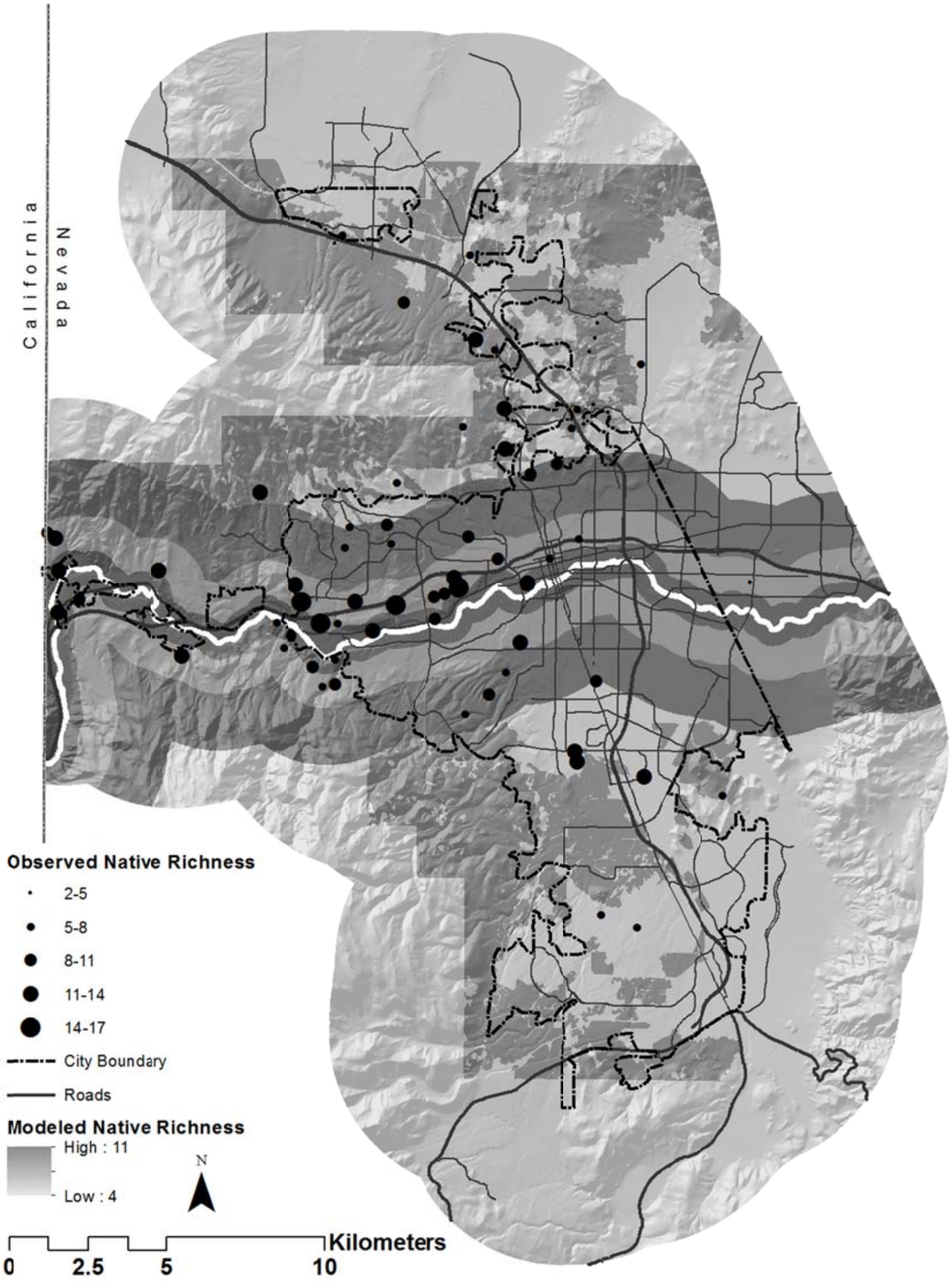

Figure 2: Predicted native species richness in Reno, NV. Darker greys represent higher richness using thresholds identified in a CART analysis. Dashed line represents the urban-rural boundary for Reno. Highways and arterial roads are in light grey. Truckee River is the bold white line bisecting Reno. Black dots show native richness observed at each point count location. Native richness is influenced primarily by distance from the Truckee River, regardless of the presense of urbanization.

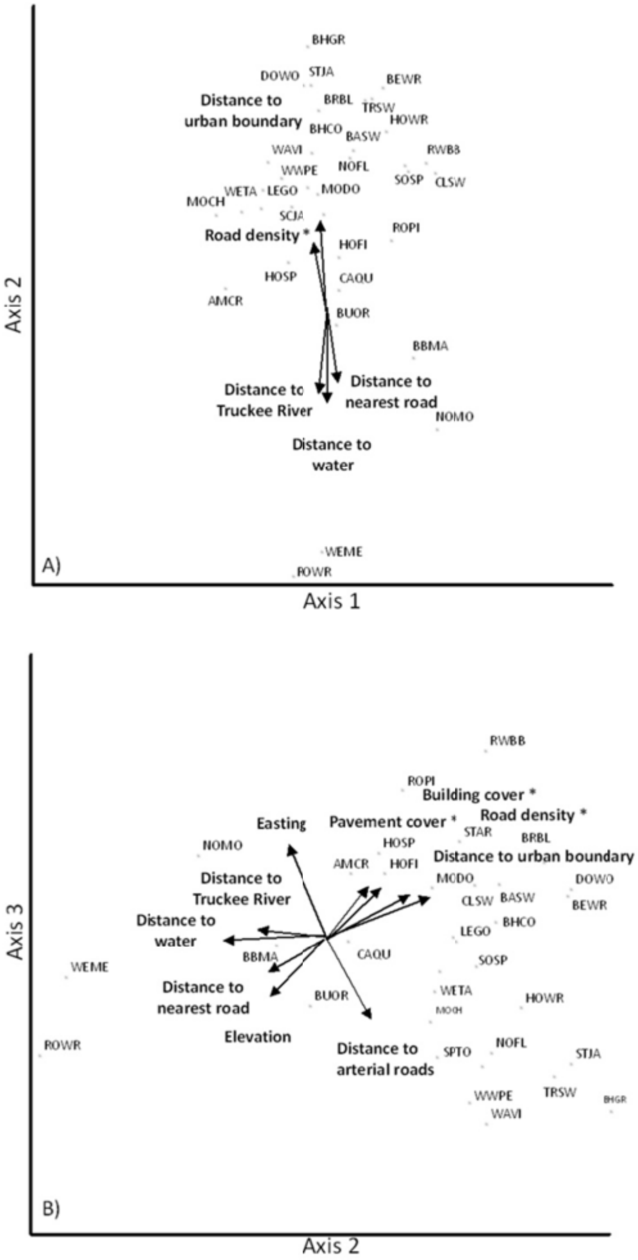

Figure 3: Plot showing relative position of different birds found in Reno, NV in multidimensional space using non-metric multidimensional scaling (NMS). A) NMS plot of axis 1 and 2 with environmental vectors as arrows. B) NMS plot of axis 2 and 3 with environmental vectors as arrows. The length and direction of the environmental vectors indicate how well those variables can be used to explain the axis. Axis 1 had low correlation values to any of the measured environmental variables, while Axis 2 and Axis 3 hightlight the importance of the urban-Truckee River gradient and the Truckee River gradient separate of urbanization, respectively. Axis 2 and 3 best describe the avian communities present in Reno, NV, with riparian birds found in the lower left corner, urban riparian birds in the middle-right, and non-riparian rangeland birds on the far left. * indicates the variable was sampled within 500m radius of point count.

Chapter 2: Impact of urban form on avian diversity along the Truckee River, USA

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Abstract

Urban riparian habitats are potentially important resources for native birds in arid ecosystems. Most studies have assessed the value of urban riparian habitat in terms of vegetation and natural resources; however, the surrounding land use may also determine the viability of urban habitat. We studied the impact of urban form, the combination of land use planning and vegetation variables, which work together to shape the urban environment, on riparian habitat in the Truckee Meadows, Nevada, USA. Land use planning explained avian species richness and abundance better than local vegetation alone, but species composition was more strongly correlated to vegetation. Avian species guilds responded differentially to surrounding land use, suggesting there may be a functional difference between land use types. The best models for bird diversity used urban form (both land use and vegetation) to describe potential habitat. Urban form describes urban habitat in ways that vegetation variables alone cannot. Studies that ignore land use planning and other socioeconomic variables are likely missing key functional differences within urban ecosystems, and may miss the potential for compatible development that encourages both biodiversity and urban growth.

Keywords: land use planning, Mantel test, Random Forests, riparian, semi-arid environment, Truckee River

Introduction

The importance of riparian habitat for biodiversity in arid environments has been well established (Naiman and Decamps 1997, Patten 1998). As riparian habitat continues to be threatened by urban sprawl, recreational use and grazing, the need for conservation has never been stronger (Knopf et al. 1988, Thompson et al. 2002, Martin et al. 2006, Arizmendi et al. 2008). Despite the immediate threat urban sprawl poses to riparian ecosystems (Luther et al. 2008), urban environments can sometimes harbor remnant riparian habitat (Long and Nair 1999, Livingston et al. 2003). For native avifauna, these remnant patches can be important habitat reserves (Oneal and Rotenberry 2009, Trammell et al. *in press*). While most studies have examined the different vegetation and environmental variables that are most important for urban riparian habitat to remain viable for birds (Seymour and Simmons 2008, Schneider and Griesser 2009), recent studies have suggested that socioeconomic and land use variables are important as well (Ortega-Alvarez and MacGregor-Fors 2009, Hostetler et al. 2011).

Socioeconomic and other land use factors often co-vary with natural features (Smallbone et al. 2011), and may act as a top down control on habitat features (Grove et al. 2006). Newer neighborhoods (housing age) were found to have higher avian richness in Chicago, suggesting that time since disturbance could impact total richness (Loss et al. 2009). Additionally, exotic richness was correlated to higher mean income in Chicago, although the opposite pattern was observed in Leipzig, where mean income correlated to an increase in native species richness, likely due to increased surrounding green (open) space (Strohbach et al. 2009). Higher mean income generally indicates active maintenance of yards and greater proportion of green (open) space, often leading to increased vegetation diversity (Kinzig et al. 2005), which can increase avian habitat. While assessing income and other socioeconomic measures have helped advance our description of the urban environment, there is still opportunity for a more comprehensive description of how biophysical and socioeconomic variables interact to structure avian diversity patterns in urban ecosystems (McIntyre and Knowles-Yanez 2000, Grove et al. 2006).

Recently, Hostetler et al. (2011) called for a more comprehensive look at the role of the surrounding landscape on urban biota. We propose that examining urban form may describe the role of the surrounding landscape, as well as provide a more comprehensive description of the urban environment as a whole. Urban form, as we define it, includes the physical environment (vegetation, water sources) as well as land use planning variables (zoning, building densities, population density, land values, etc), that combine to create the overall form of urbanization (Figure 1). Although urban form is not a new concept to planners, and it has been used to describe the urban environment previously (Tratalos et al. 2007, Bramley and Power 2009), few studies have looked at both vegetation and land use planning to describe the urban form (see Ortega-Alvarez and MacGregor-Fors 2009 for an exception). By studying the urban form, we might better understand the relationship within and between the various socioeconomic and biophysical variables that formulate an urban environment (Dow 2000), especially as biodiversity is likely to respond differently to the various urban components beyond vegetation that create the urban environment (Alberti 2005). Furthermore, land use and other socioeconomic variables that determine the urban form may be particularly important in determining avian habitat in semi-arid systems where vegetation structure (Mennis 2006) and net primary productivity (Buyantuyev and Wu 2009) vary as a function of urban development.

We are interested in how well urban form, specifically the combination of land use planning and local vegetation, describes avian diversity patterns in the urbanized riparian habitat along the Truckee River, Nevada, USA. Trammell et al. (*in press*) found avian diversity to be associated with distance to the Truckee River, with highest diversity occurring within 500m of the river, regardless of the presence of urbanization. However, the effects of urbanization could not be separated from the effects of the Truckee River, potentially because of the variation in urban land use (residential, commercial, industrial) along the Truckee River. We hypothesize that in urban riparian habitat, urban form will better predict avian diversity than vegetation alone. We test this hypothesis by comparing how well 1) land use planning, 2) local vegetation, and 3) urban form (land use planning and vegetation together) describe avian diversity patterns along the Truckee River in the cities of Reno and Sparks, NV, USA. We also predict that land use planning (as a subset of urban form) will predict avian diversity better than vegetation alone. Our goal is to provide more specific management recommendations that utilize existing land use planning concepts, in addition to providing a more comprehensive description of the urban environment (McIntyre and Knowles-Yanez 2000).

Methods

Study Area

The Truckee Meadows is located on the western edge of the Great Basin at the foothills of the Sierra Nevadas, in the western United States (39° 31’ N, 119° 48’ W, Figure 2). The cities of Reno and Sparks represent the two primary urban environments, with a total estimated population of 309,380 in 2009 (Hardcastle 2010). Vegetation communities are typical of a high elevation semi-arid desert, with sagebrush steppe occupying most of the landscape, and cottonwood riparian woodland along the Truckee River. The Truckee River is fed almost entirely by snowmelt from the Sierra Nevada Mountains, and serves as the permanent water source for the metropolitan area. Flows become significantly reduced in the late summer months, but base flow is around 8.5 cubic meters per second (USGS 2010).

Like many arid cities in the western U.S., the Truckee Meadows is a relatively young urban environment, which has preserved some remnant riparian habitat. However, the population of the Truckee Meadows is forecasted to continue to grow and perhaps even double over the next 40 years (TMWA 2010). The young urban age and expected future growth make the Truckee

Meadows an ideal place to study avian relationships in a smaller urban environment prior to its build out (Grimm et al. 2000, Garaffa et al. 2009).

Bird Observations

Point counts were conducted in riparian habitat along the Truckee River within the city boundaries of Reno and Sparks, NV. Riparian patches within 500m of the Truckee River were digitized using 1m resolution digital orthophotography obtained from the National Agriculture Inventory Program (NAIP), and validated in the field. Thirty point counts were randomly located in the riparian patches with a minimum of 250m separation to limit the probability of double counting birds. Birds were surveyed three times during the breeding seasons (May-June) in 2009 and 2010. All surveys lasted 10 minutes, following a three minute calm down period, and were performed by the same observer (J. Trammell). Variable-circle sampling (Reynolds et al. 1980) was utilized to maximize sampling area since riparian habitats often occur as linear patches that are not regularly shaped. All point counts were done within four hours of sunrise and included all birds identified by sight and sound. Flyovers and waterfowl were not included in any of the analyses.

We used multiple metrics for quantifying avian richness and abundance based on natural history, resident status, habitat preference and life history traits. Urban riparian habitat has been found to be important for migratory birds (Pennington et al. 2008), so Neotropical migrant richness and abundance habitat relationships were modeled. Species that were classified as either obligate or dependent riparian species (Rich 2002) were also compared to vegetation and land use planning variables. Life history traits may determine the success of native birds in urban environments (Leston and Rodewald 2006, Blair and Johnson 2008), so habitat relationships were modeled for two reproductive guilds (single brood species and multiple brood species). Finally, ground nesting habitat could be influenced disproportionately by land use (Borgmann and

Rodewald 2004, Lenth et al. 2006), so nesting location (low vs. mid-canopy) species richness and abundance habitat preferences were modeled. We averaged the number of each species over the three counts per year and between years to form an index of abundance (Hennings and Edge 2003). Nesting preference and brood information were taken from the Birds of North America online (http://bna.birds.cornell.edu/bna/).

Local Vegetation Characteristics

Vegetation variables describing the habitat condition at each point count location were collected in the spring and summer of 2009 (Table 1). All vegetation variables unless otherwise noted were collected within a 25m radius of the census point. Vegetation variables focused on tree canopy, composition and density, as vertical structure is thought to be of primary importance for urban bird habitat (Emlen 1974, Green and Baker 2003). Normalized Difference Vegetation Index (NDVI), calculated from Landsat TM imagery, was measured at the 30m pixel closest to the center of the point count (referred to as NDVI). Average NDVI was also calculated for a 100m radius surrounding the point (referred to as 100mNDVI), to capture the vegetation productivity at multiple scales for each site (Bino et al. 2008).

Land Use Planning

Multiple land use planning variables related to land value, zoning and road density were used to describe the built urban environment (Table 1). Most variables were sampled at multiple spatial scales in order to explore the micro, macro, and landscape context (Saab 1999). Land values were used to indicate socioeconomic status (Martin et al. 2004, Kinzig et al. 2005) and were obtained from a parcel database acquired from the Washoe County GIS portal (www.co.washoe.nv.us). Land values were calculated at 100m from the point count to capture immediate land values, and at 500m to capture neighborhood land values. Zoning variables, used as the primary measure of surrounding land use (Merenlender et al. 2009), were simplified from the Washoe County parcel database land use codes to vacant (undeveloped), single family (1 dwelling per parcel), multiple family (2-4 dwellings per parcel), high density residential (> 5 housing dwellings per parcel), commercial, industrial, open space (including parks) and undesignated (road rights of way and previously cleared for development). Land use categories were simplified to this Anderson level II-type classification (Anderson et al. 1976) for easier comparison to other cities (McIntyre and Knowles-Yanez 2000). Percent of each type of surrounding land use was calculated at 100m, 500m and 1000m from the point count locations. Relative population density, used as a measure of daily disturbance, was calculated from the number of bedrooms in residentially zoned parcels. Building density was calculated based on number of buildings per parcel, and building square footage was calculated by summing the total building square footage for each parcel (Pennington et al. 2008). Zoning information, relative population density, building density and building square footage were all calculated using the Washoe County parcel database. Road density (Hennings and Edge 2003) was calculated using a road network shapefile acquired from the Washoe County GIS data portal by summing the length of each road segment within a one mile search radius and dividing it by the area of the circle. Major road density was calculated the same way, using only freeways, highways and arterial roads. Patch area and perimeter were calculated in GIS to measure the importance of habitat shape in urban habitat suitability (Mason et al. 2007).

Random Forests and Regression Tree Models

We used regression tree modeling to quantify how different metrics of richness and abundance responded to the urban environment. Regression tree models can be used to uncover multiscaled and nested relationships (De'ath and Fabricius 2000) which could be important when assessing land use planning and vegetation variables together, and can be used to identify non-linear relationships (i.e. thresholds) which can be particularly useful for land use planning. Random Forests (Breiman 2001, Evans and Cushman 2009) utilizes the regression tree approach to provide statistically robust rankings of the relative predictive power of the response variables. Random Forests works as a learning technique where bootstrap samples are used to construct many (in this case 1,000) regression trees. For each tree, a random subset of the variables is used, and the resulting tree is tested against data not used in the construction of the tree (called “out-of-bag” data). Random Forests then ranks the variables that are most often chosen to split the data, which served as our primary measure of variable importance for the richness and abundance models. For each of our richness and abundance metrics we constructed regression trees using 1) the top five vegetation variables, 2) the top five land use planning variables, and 3) the top seven overall variables to describe the urban form. This aided in understanding the direction of influence each variable had on our responses, and in our understanding of nested responses to both vegetation and land use planning factors. Cost-complexity was used to minimize over-fitting. Variance explained for each tree was calculated by dividing the root deviance by the sum of the deviances left over at each terminal node and subtracting from one (De'ath and Fabricius 2000).

Mantel and Partial-Mantel Tests

We used a combination of Mantel and partial-Mantel tests to assess the relative contribution of vegetation and land use planning variables in shaping avian community structure (McCune and Grace 2002). Mantel test assesses the degree of association between two dissimilarity matrices, while partial-Mantel test calculates the association between two matrices while accounting for additional dissimilarity matrices. The significance is assessed by comparing the correlation coefficients to values generated by randomizing the matrix many times (in this case 15,000). The advantage of using Mantel tests is that it allows inference without normality assumptions, and the partial-Mantel test can help partition the ecological variation into meaningful measures (Legendre and Fortin 1989). Although there is little discussion about variable selection in the Mantel test literature, we reduced the number of variables used to create the vegetation and land use planning dissimilarity matrices. We simplified our matrices to include the most important variables, based on how well individual variable dissimilarity matrices correlated to the species composition matrix (Appendix 1). Variables that helped describe community composition with > 90% confidence (p-value < 0.1) were then used to create simplified vegetation and land use planning matrices. We ran simple Mantel tests to examine the relationship between avian composition and vegetation, and avian species composition and land use planning variables. We used partial-Mantel test to assess the relationship between avian composition and vegetation while accounting for land use planning and avian composition and land use planning while accounting for vegetation, and all combinations given space. Spatial coordinates were included to ensure any correlations identified were not due to spatial autocorrelation. Species composition, vegetation and land use planning dissimilarity matrices were calculated using the Bray-Curtis similarity index, while the spatial dissimilarity matrix was calculated using Euclidean distance (Krebs 1999). We present the Mantel r, a value that estimates the intensity (similar to the Pearson r) of the relationship between dissimilarity matrices, and the associated p-value.

Results

Avian Richness and Abundance

Fifty-nine species (four exotic species, fifty-five native species) were included in our analysis (Table 2). House sparrow (*Passer domesticus*) was the most abundant species (n=113), followed by American robin (*Turdus migratorius*, n = 83) and European Starling (*Sturnus vulgaris,* n = 77). Twelve species were identified as Neotropical migrants, while fifteen were identified as either obligate or dependent riparian species (Rich 2002). Twenty species were identified as only producing a single brood per mating season, and thirty-nine species were classified as having more than one brood per breeding season. Thirty-nine mid-canopy nesting species and fifteen low-canopy/ground nesting species were also observed.

Regression Tree Habitat Models

The Random Forests analyses consistently ranked land use planning variables measured at the 1,000m radius higher than those at 100m and 500m, which is consistent with other urban landscape studies (Rodewald and Bakermans 2006, Ryder et al. 2010). Overall, the regression trees explained a large amount of the variation in species richness (mean of 71% variance explained) and abundance (mean of 61% variance explained; Tables 3 & 4). In general, land use planning variables explained more variation than vegetation variables, and the urban form models explained the most variation. Exotic richness was the only model best described by vegetation. In every other model, land use planning alone or urban form explained more variation. Variance explained ranged from 25% (for exotic species abundance using vegetation only) to 82% (for single brood richness urban form model).

Vegetation

Mean tree cover was used in four of the final models: overall avian abundance, single brood species abundance, multiple brood species richness, and low nesting species richness. In all four models, species richness and abundance was negatively correlated to increases in tree cover. Increased abundance of exotic trees was positively correlated to exotic species richness and negatively correlated to abundance of low-nesting species. Taller trees (maximum tree height) had a positive relationship to both overall and native species abundance. Higher NDVI showed a positive correlation to mid-canopy nesting species abundance up to a threshold (0.28), but had a negative correlation to riparian species abundance.

Land Use Planning

Land use planning variables described more variance in species richness and abundance than vegetation. Major road density had the most consistent association with avian richness and abundance, as it was used in 11 of the 18 final models (Table 3), and was always negatively related to species richness and abundance (Figure 3). Undesignated zoning was used in 8 of the final models, and was positively related to exotic species abundance, but negatively related to overall species richness, native species richness and abundance, Neotropical species richness and abundance, riparian species richness and abundance, single brood species richness and mid-canopy nesting species richness. High density residential zoning was used in 6 of the final models, and like major road density, had a negative association with species richness and abundance. Vacant zoning had a positive influence on three final models: overall, native and mid-canopy nesting species richness. Population density was used in three of the final models, showing a positive relationship to multiple brood species richness, and a negative relationship to low-nesting species richness and abundance (Table 3).

Species Composition

Four vegetation variables (NDVI, 100mNDVI, exotic tree abundance, average tree height) were significantly correlated with species composition, while seven land use planning variables were significantly correlated with species composition (multi-family zoning at 500m, major road density at 500m, perimeter of habitat, open space zoning at 1,000m, patch area, commercial zoning at 500m, and high-density family zoning at 500m; Appendix 1). Overall, species composition was correlated with both the vegetation and land use planning matrices (Table 5). Vegetation as a whole (all vegetation variables) was moderately correlated to avian species composition ($r = 0.14$, $p = 0.035$). When only the top vegetation variables were used, the relationship was stronger ($r = 0.25$, $p = 0.0014$). No relationship was found between the full land use planning variables matrix and species composition ($r = 0.015$, $p = 0.415$). However, when only the top land use planning variables were used, there was a moderate correlation to avian species composition ($r = 0.14$, $p = 0.035$). Partial-Mantel tests revealed little interaction between the different matrices, as correlations were not improved when the partial effects of land use, vegetation and space were included (Table 5).

Discussion

Importance of Urban Form

This analysis provides evidence for the importance of land use planning when describing avian habitat within urban environments, especially when considered in conjunction with vegetation to describe the urban form. Both the Random Forests and Mantel tests suggest that vegetation and land use planning variables are important for defining the urban environment. Comparison of the vegetation vs. land use planning models highlights the potential for overlooking important urban variables that shape avian responses. Our prediction that urban form would better describe avian diversity patterns proved true across the different metrics of richness and abundance, as the best models included both vegetation and land use planning variables. Likewise, our prediction that land use planning variables alone would better predict species richness and abundance held true. However, vegetation seems to play a more important role in shaping community structure than land use planning. Taken together, this analysis suggests that land use planning may drive overall habitat availability and higher-level properties of community structure (such as diversity indices), but vegetation most likely determines species composition. Although the relative importance of land use planning and vegetation changed with each diversity metric, there are important trends that can help us understand the cumulative impact of vegetation and land use planning on urban bird diversity.

Important Vegetation Characteristics

Our models suggest most species guilds prefer lower tree cover, which highlights the importance of the landscape context (Rosenberg et al. 1987, Saab 1999, Whittaker et al. 2005). Riparian birds in the Great Basin tend to prefer open canopy riparian forests (lower tree cover) with tall, mature cottonwood trees (Lynn et al. 1998, Warkentin and Reed 1999). Average tree height also showed a positive relationship to many of the richness and abundance groups, as well as species composition, suggesting that most species appear to be focusing on habitats with similar vegetation structure to natural riparian forests. NDVI proved to be important to multiple models of richness and abundance (both immediate and surrounding), and species composition. Higher NDVI in arid environments typically indicates intensively irrigated vegetation such as lawns (Buyantuyev and Wu 2009), which may explain why riparian species showed a negative relationship to NDVI, as natural riparian habitat doesn't typically have dense grass understory. Mid-canopy nesting species richness was positively related to NDVI, but only up to a threshold (0.28), suggesting that even though there was a positive correlation, mid-canopy nesting species may have the same overall response as riparian species (Figure 4). Finally, the preference of exotic trees by exotic avifauna is well supported in other studies (Germaine et al. 1998, Donnelly and Marzluff 2004), but the avoidance of habitats with abundant cottonwoods deserves more research, as it may point to increased competition or some mechanism that could be used to discourage exotic species. These results suggest that urban reserves should focus on mimicking the canopy structure of natural environments, even though this may not be as aesthetically appealing (Bark et al. 2009).

Important Land Use Planning Variables

The top variable in describing avian diversity along the Truckee River was major road density. This includes freeways, highways and arterial roads that are found throughout the Truckee Meadows. The density of these roads was negatively related to almost all of the metrics of diversity, and in most cases represented the top variable in the regression tree analysis. This result corroborates what has been found in other studies (Katti and Warren 2004, Francis et al. 2009) although few studies have separated major roads from other roads. Major road density was also correlated to species composition (Appendix 1), suggesting major roads need to be a top consideration for land use planning. Major roads are significant linear features that can lead to increased road strike mortality, increased noise, and represent potential barriers to movement

(Tremblay and St Clair 2009). Road density (a separate variable) showed only a marginal relationship to any diversity metric, suggesting that not all roads are equal in their impact on avian habitat. This could be especially important as rivers can also serve as a barrier to movement (Tremblay and St Clair 2009), potentially isolating small fragments of habitat between the Truckee River and major roads.

To add further evidence to the differential impact of major vs. other roads, undesignated zoning was also a top predictive variable. In the Truckee Meadows, this zoning typically refers to lands associated with different developments but not zoned anything specific (i.e. major road right-of-ways) or lands that have been cleared for future development. Thus, undesignated land use represents a highly modified habitat with little or no vegetation, often associated with major roads. Habitats with even a moderate amount (i.e. > 38%; Figure 4) of this land use near riparian areas had far less species richness and abundance, which could be due to the greater overall disturbance undesignated zoning represents (lack of vegetation, road noise, etc). Zoning represents a political boundary and the transition between one zoning type and another may be too abrupt for birds to overcome (Hodgson et al. 2007). The relatively sharp reduction in species richness and abundance in response to undesignated zoning (Figures 3 & 4) adds support to this observation. The categorical nature of land use planning variables, and the potential abrupt habitat change it represents, needs to be further considered in urban ecological studies, especially when defining the role of the surrounding landscape (Hostetler et al. 2011).

The positive response of overall, native and mid-canopy nesting species richness to vacant lands deserves more research, as these lands may represent small habitat reserves within the urban environment (Donnelly and Marzluff 2004, Pautasso and Weisberg 2008). Although vacant lands are often lumped in with open (green) space, the distinction between the two is important in the Truckee Meadows. First, the average size of a vacant parcel in the Truckee Meadows is a little over 2 hectares and typically has remnant rangeland vegetation. The average size of an open space parcel is 29 hectares and includes parks that are irrigated, as well as native vegetation patches. The fact that open space was not used in any of the richness and abundance models, even though it was identified as a top predictor by the Random Forests analysis, suggests that open space zoning in the Truckee Meadows may not be an important variable for many bird species, or may be too variable to be used as a richness or abundance predictor. The positive correlation between open space and species composition suggests that open space might be important for species not represented in the guilds modeled here, or could highlight the fact that in most cases open space is not actively managed for habitat (Lenth et al. 2006) and may only attract urban adapted species. More research into the structure and functionality of vacant vs. open space lands needs to be assessed to understand the functional differences between these two land uses, especially in the context of different species assemblages.

Finally, the differential response of the reproductive guilds (single brood vs. multiple brood species) to the different land uses highlights important mechanistic questions (Shochat et al. 2006). Multiple brood species richness correlated positively to higher relative human population densities, while single brood species abundance was highest in industrial areas with smaller buildings. Since industrial areas tend to have less human activity (but higher mechanical activity and noise) this separation may suggest that single-brood species have a preference for reduced human activity (Miller and Hobbs 2000) at the potential cost of noise. The positive response of multiple-brood species to increased human density supports previous findings that reproductive plasticity helps birds adapt to urban environments with persistent human disturbances (Blair 2004). The negative response of native species abundance to building size may lend support to the finding that larger buildings may increase window collisions (Klem et al. 2009). Alternatively, riparian species richness increased in areas with moderate commercial zoning. One possible explanation could be related to the timing of green-up and its relationship to urban heat island effects (Shustack et al. 2008). Urban heat island effects are likely to vary by land use, with the higher temperatures being associated with those land uses that have more impervious cover (ie commercial zoning) than others (Weng et al. 2006). Riparian species may be attracted to habitat where plants green-up earlier, even within commercial areas. However, the need for additional research is clear, as these only represent a few examples of how land use planning may impact the function of urban habitats.

Conservation Implications

Ecologists and conservation planners have a great opportunity to team up with urban planners to develop land use plans that do not compromise avian diversity (Jim 2011). By examining the reproductive, nesting and habitat diversity of urban birds, ecologists and conservation planners can help develop land use plans that do not disproportionately select against different avian groups (Jokimäki et al. 2011). This study suggests that major roads and the cleared lands associated with undesignated zoning need to be kept away from riparian habitat, not only to protect habitat but also to discourage exotic species. This is particularly important when considering urban reserves for species of concern (Donnelly and Marzluff 2004, Kadlec et al. 2008, Hostetler et al. 2011). Likewise, the non-response (i.e. no groups responded negatively to general road density), and sometimes positive response (i.e. riparian birds increasing in commercial zoning) of guilds to different land uses highlights the opportunity for compatible growth plans to be developed for the region.

Assessing the impacts of urban form on urban habitats helps us better understand the complex nature of urban environments, and provides a way to more effectively develop land use policies to promote urban biodiversity (McIntyre and Knowles-Yanez 2000). Land use planning variables describe the urban environment in ways that vegetation variables alone cannot, and they are important in shaping the function and structure of urban habitat (Hostetler et al. 2011). Major roads, undesignated zoning, and high density residential zoning all appear to reduce the viability of urban habitats. Assessing the functional relationship of land use planning, vegetation and bird diversity can help us better understand how the different components of an urban environment create the urban landscape (Cadenasso et al. 2007).

Future Research

Although this paper assessed the importance of including both planning and vegetation variables, the interrelationship between these variables needs to be further assessed (Martin et al. 2004). Results from this study indicate a potential relationship exists between vegetation composition and land use planning, but this needs to be explored in a more mechanistic manner. Furthermore, as our understanding of land use planning in determining habitat viability increases, alternative scenarios of land use policies need to be developed as a way to test habitat relationships in the future (Hepinstall et al. 2008). Policies need be created that guide development in urban environments to emphasize the variables that promote urban habitat, but they also require careful consideration of future growth. Modeling these relationships into the future can provide a test of whether desired policies would be useful both in the context of environmental policy formation and in the understanding of how biological resources change with growing urban environments.

Conclusion

Effective conservation of urban biodiversity will require novel approaches to thinking about ecosystems (Grimm et al. 2000). A better understanding of urban ecology requires substantial knowledge about the physical system and the social and economic systems that determine the form and function of urban environments (Tarsitano 2006). This research has documented the importance of urban form in determining bird diversity in an urban landscape, and specifically that land use, along with other urban planning variables, predicted avian richness and abundance better than vegetation variables alone. Describing urban environments in terms of urban form can help ecologists provide specific planning-based recommendations to promote urban bird diversity.

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	Variable	Description	Method
Vegetation Variables	Pine	Total number of coniferous trees	F
	Cottonwood	Total number of cottonwood trees	F
	Willow	Total number of individual willows	F
	ExoticTree	Total number of exotic tree species	F
	DeadTree	Total number of standing dead trees	F
	TotalTree	Total number of trees	F
	MnTreeHt	Mean tree height for all trees	F
	MaxTreeHt	Maximum tree height for all trees	F
	MnTreeCov	Mean tree cover	F
	NDVI	Normalized Difference Vegetation Index measured at the pixel closest to the point count	S
	100mNDVI	Normalized Difference Vegetation Index averaged for a 100m radius from the point	S
Land Use Planning Variables	Area	Patch area (hectares)	G
	Perimeter	Perimeter of patch (m)	G
	AP_Ratio	Ratio of area to perimeter	G
	Values	Average land values for 100m and 500m radius from the point counts	G
	Vacant	Percent of vacant land, includes active development,	Ga
	SF	Percent of single family residence zoning, single unit per parcel	Ga
	MF	Percent of multiple family zoning, up to 4 units per parcel	Ga
	HDF	Percent of high density residential zoning, 5 units or more per parcel	Ga
	Comm	Percent of commercial zoning, including office, casino and other general commercial	Ga
	Indust	Percent of industrial zoning, including general and commercial industrial	Ga
	OS	Percent of open/green space zoning, comprised mostly of parks and common areas	Ga
	Ag	Percent of agricultural zoning, including cultivation, grazing and pasture lands	Ga
	UN	Percent of undesignated/unknown zoning	Ga
	RelDens	Relative density of people estimated from # of bedrooms in buildings	Gs
	BuildDens	Building density	Gs
	RoadDens	Road density	Gs
	ArtDens	Major road density	Gs
	BuildSF	Total square feet of buildings	Gs

Table 1: List of vegetation and land use planning variables collected along the urbanized portion of the Truckee River, NV, USA, to describe urban bird diversity patterns. F = variable was collected in the field within 25m of the point count. S = generated using a Landsat 5 image from May 2, 2009. G = variable was generated in a GIS, Gs = variable measured within 500m and 1,000m of point count, Ga = variable measured within 100m, 500m and 1,000m of point count location.

Common Name	*Scientific Name*	B	N
American Crow	*Corvus brachyrhynchos*	-	m
American Dipper	***Cinclus mexicanus***	+	l
American Goldfinch	***Spinus tristis***	+	m
American Robin	*Turdus migratorius*	+	m
Anna's Hummingbird	*Calypte anna*	-	m
Ash-throated Flycatcher	*Myiarchus cinerascens*	-	m
Barn Swallow	*Hirundo rustica*	+	l
Black-billed Magpie	*Pica hudsonia*	-	m
Black-chinned Hummingbird	*Archilochus alexandri*	-	m
Belted Kingfisher	***Ceryle alcyon***	-	m
Bewick's Wren	***Thryomanes bewickii***	+	l
Brown-headed Cowbird	*Molothrus ater*	-	m
Black-headed Grosbeak	*Pheucticus melanocephalus*	-	m
Brewer's Blackbird	*Euphagus cyanocephalus*	-	m
Band-tailed Pigeon	*Columba fasciata*	-	m
Bullock's Oriole	***Icterus bullockii***	-	m
Bushtit	*Psaltriparus minimus*	-	m
California Quail	*Callipepla californica*	+	l
Cedar Waxwing	*Bombycilla cedrorum*	+	m
Chipping Sparrow	*Spizella passerina*	+	m
Cliff Swallow	*Petrochelidon pyrrhonota*	-	l
Common Yellowthroat	***Geothlypis trichas***	-	l
Downy Woodpecker	*Picoides pubescens*	-	m
Eurasian Collared Dove	*Streptopelia decaocto*	-	n/a
European Starling	*Sturnus vulgaris*	+	n/a
Fox Sparrow	*Passerella iliaca*	+	l
Gray Flycatcher	*Empidonax wrightii*	+	m
Hairy Woodpecker	*Picoides villosus*	-	m
House Finch	*Eremophila alpestris*	+	m
House Sparrow	*Passer domesticus*	+	n/a
House Wren	***Troglodytes aedon***	+	m
Lesser Goldfinch	***Spinus psaltria***	+	m
MacGillivray's Warbler	***Oporornis tolmiei***	-	l
Mountain Chickadee	*Poecile gambeli*	-	m
Mourning Dove	*Zenaida macroura*	+	n/a
Northern Flicker	*Colaptes auratus*	-	m
Northern Mockingbird	*Mimus polyglottos*	-	m
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	+	l
Olive-sided Flycatcher	*Contopus cooperi*	-	m
Pacific-slope Flycatcher	*Empidonax difficilis*	-	m
Red-winged Blackbird	*Agelaius phoeniceus*	+	l
Rock Pigeon	*Columba livia*	+	n/a
Rock Wren	*Salpinctes obsoletus*	-	l
Song Sparrow	***Melospiza melodia***	-	l
Spotted Towhee	*Pipilo maculatus*	-	l
Steller's Jay	*Cyanocitta stelleri*	-	m
Tree Swallow	***Tachycineta bicolor***	-	m
Vaux's Swift	*Chaetura vauxi*	-	m
Violet-green Swallow	*Tachycineta thalassina*	-	m
Warbling Vireo	***Vireo gilvus***	-	m
White-breasted Nuthatch	*Sitta carolinensis*	-	m
Wilson's Warbler	***Wilsonia pusilla***	-	l
White-throated Swift	*Aeronautes saxatalis*	-	m
Western Kingbird	*Tyrannus verticalis*	-	m
Western Scrub Jay	*Aphelocoma californica*	-	l
Western Tanager	*Piranga ludoviciana*	-	m
Western Wood-Pewee	***Contopus sordidulus***	-	m
Yellow Warbler	***Dendroica petechia***	-	m
Yellow-rumped Warbler	*Dendroica coronata*	+	m

Table 2: List of birds observed along the urbanized part of the Truckee River, NV during the breeding seasons of 2009 and 2010. Bold represents riparian dependent/obligate species according to Rich (2002). The "B" column represents number of broods, with (-) corresponding to species that only have one brood per year and (+) corresponding to species that have more than a single brood per year. The “N” column corresponds to nesting preference location: l = low or ground nesting and m = mid-canopy nesting.

		Overall		Native		Exotic		Neotropical		Riparian		Single Brood		Multiple Broods		Low Nesters		Mid Nesters	
		Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun	Rich	Abun
Vegetation Variables	Mean Tree Cover		-		^								-	-	^	-			
	Exotic Tree Abun					+				^			^				-	^	
	Maximum Tree Ht		+		+									^					^
	NDVI										-			^				^	+
	Cottonwood Abun					-							^						
	Dead Tree Abun					^									-				
	NDVI @ 100m		^																^
	Mean Tree Ht									^									
	Pine Abun	^																	
Land Use Planning Variables	Major Road Density	-	^	-	-	^	^	-	-	-	-	-	-			^		-	-
	Undesignated	-		-	-	^	+	-	-	-	-	-				^		-	
	High Density-Family	^		^			-	-	-	-	-	-				^		^	
	Vacant	+		+								^	^					+	
	Population Density													+		-	-		
	Building Size	^		^	-							^	-	^			^		^
	Building Density		+					^	^						+				
	Industrial												+	+	^		^		
	Area														+		-		
	Commercial	^			^	^				+	^	^						^	^
	Multi-Family			^			+	^	^		^					^			
	Single-Family			^				-	^			^				^	^		
	Perimeter		-				^								^		^		
	Road Density						^	^	^		^								
	Open Space				^	^													^
	Area-Perimeter Ratio									^									

Table 3: List of top variables identified by Random Forests and modeled using regression trees for different metrics of avian diversity along the urbanized section of the Truckee River, NV. The headings denote the different avian diversity models. ^ represents variables identified by the Random Forests models, but were not used in the final regression trees. (-) represents variables that were used in the final tree models and had a negative impact on the richness or abundance model. (+) represents variables that were used in the final tree models and had a positive influence on the richness or abundance model. Variables are ordered in terms of how many times they were used in model construction. Land use planning variables were used more frequently and led to models that explained more variance than vegetation variables alone.

		Environmental		Land Use Planning		Combined	
		RMD	Var. Exp.	RMD	Var. Exp.	RMD	Var. Exp.
Overall	Richness	9.1	60.3%	4.5	79.5%	4.5	79.5%
	Abundance	67.3	45.7%	79.5	38.3%	64.2	50.2%
Native	Richness	11.1	54.4%	4.2	81.9%	4.2	81.9%
	Abundance	21.8	68.3%	28.7	60.1%	16.9	76.5%
Exotic	Richness	0.2	63.7%	0.2	46.0%	0.2	55.7%
	Abundance	30.3	24.9%	20.8	46.4%	21.5	44.7%
Neotropical	Richness	5.9	31.8%	2.6	68.4%	2.1	75.4%
	Abundance	7.9	50.0%	3.2	80.7%	3.2	80.7%
Riparian	Richness	4.7	46.4%	3.3	63.3%	3.3	63.3%
	Abundance	5.6	64.2%	4.2	73.4%	4.2	73.5%
Single Brood	Richness	4.2	73.8%	2.7	82.2%	2.7	82.2%
	Abundance	14.4	54.1%	6.8	78.2%	6.8	78.2%
Multiple Broods	Richness	1.0	46.5%	0.7	63.3%	0.7	65.0%
	Abundance	56.4	35.8%	52.5	37.7%	50.2	40.5%
Low Canopy Nesters	Richness	2.2	47.0%	1.9	52.7%	1.6	59.9%
	Abundance	13.2	38.0%	12.4	41.9%	12.8	39.6%
Mid-Canopy Nesters	Richness	4.3	61.5%	2.3	78.4%	2.3	78.4%
	Abundance	14.5	61.0%	15.4	60.4%	14.5	61.1%

Table 4: CART model results showing the predictive power of vegetation, land use planning, and urban form in describing avian diversity along the urbanized section of the Truckee River, NV. The urban form models explained the most variance overall. RMD = residual mean deviance, var. exp. = variance explained calculated by subtracting the summed left over deviance from the root deviance and subtracting that by one.

Test	Mantel r	p-value
Birds ~ Vegetation	0.251	0.001
Birds ~ Vegetation + LUC	0.246	0.001
Birds ~ Vegetation + Space	0.233	0.004
Birds ~ Vegetation + LUC + Space	0.228	0.004
Birds ~ LUC + Space	0.161	0.021
Birds ~ LUC + Vegetation + Space	0.152	0.031
Birds ~ LUC	0.143	0.036
Birds ~ LUC + Vegetation	0.134	0.047
Birds ~ Vegetation (Full)	0.143	0.036
Birds ~ LUC (Full)	0.015	0.415

Table 5: Mantel and partial Mantel results comparing vegetation, land use planning, and spatial location in describing species composition along the urbanized section of the Truckee River, NV.

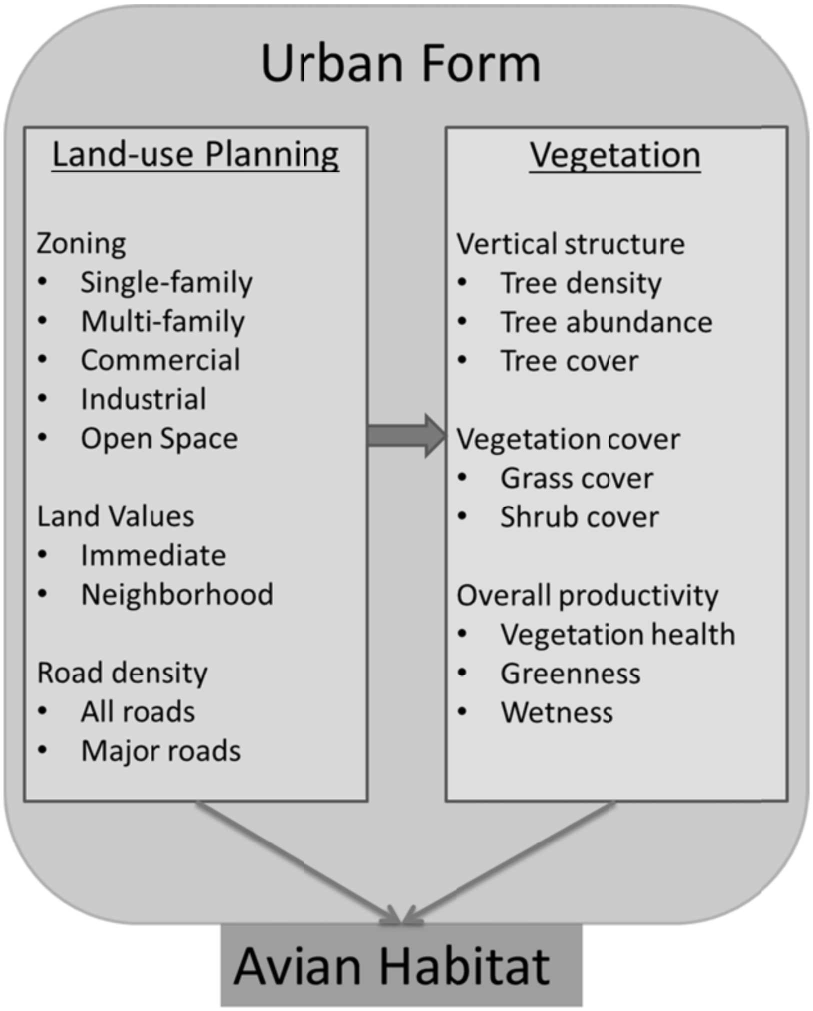

Figure 1: Conceptual model of the interrelationship between land use planning and vegetation variables within an urban environment described by urban form. Assessing the impacts of urban form on habitat allows for both the direct and indirect impacts of land use planning to be modeled.

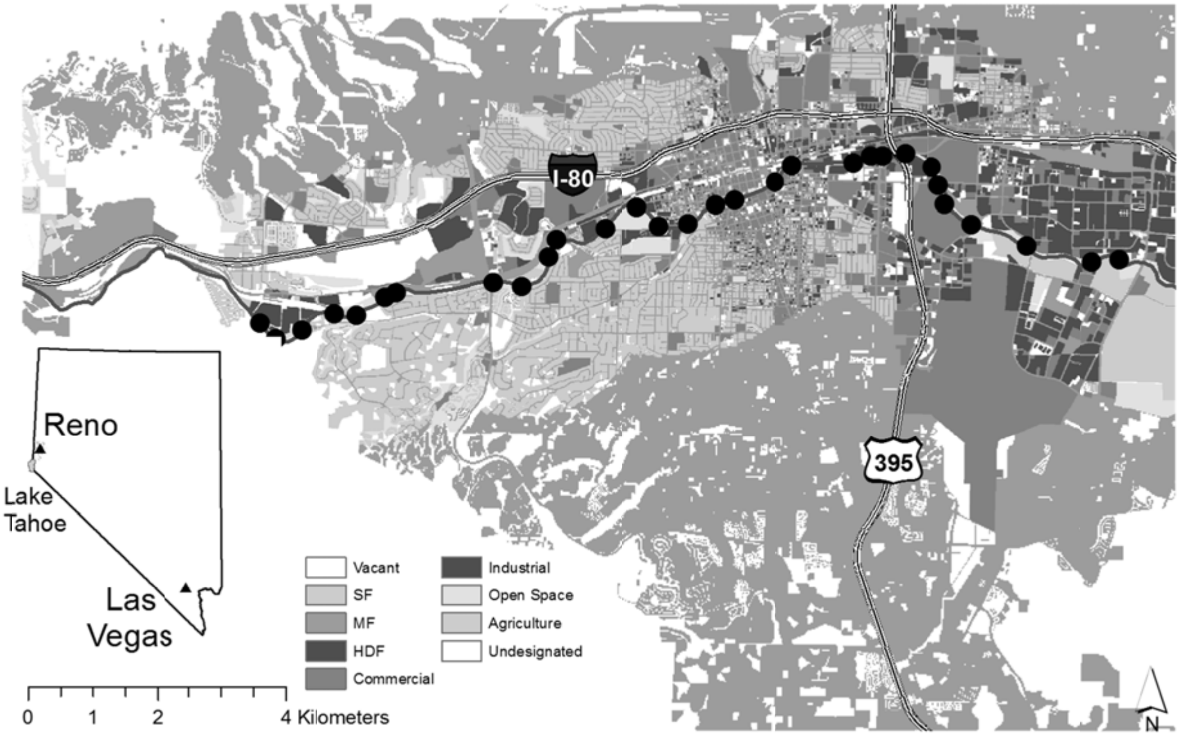

Figure 2: Avian point count locations along the urbanized portion of the Truckee River in Reno and Sparks, NV, USA. Land use zoning only shown for areas within 1,000m of the Truckee River.

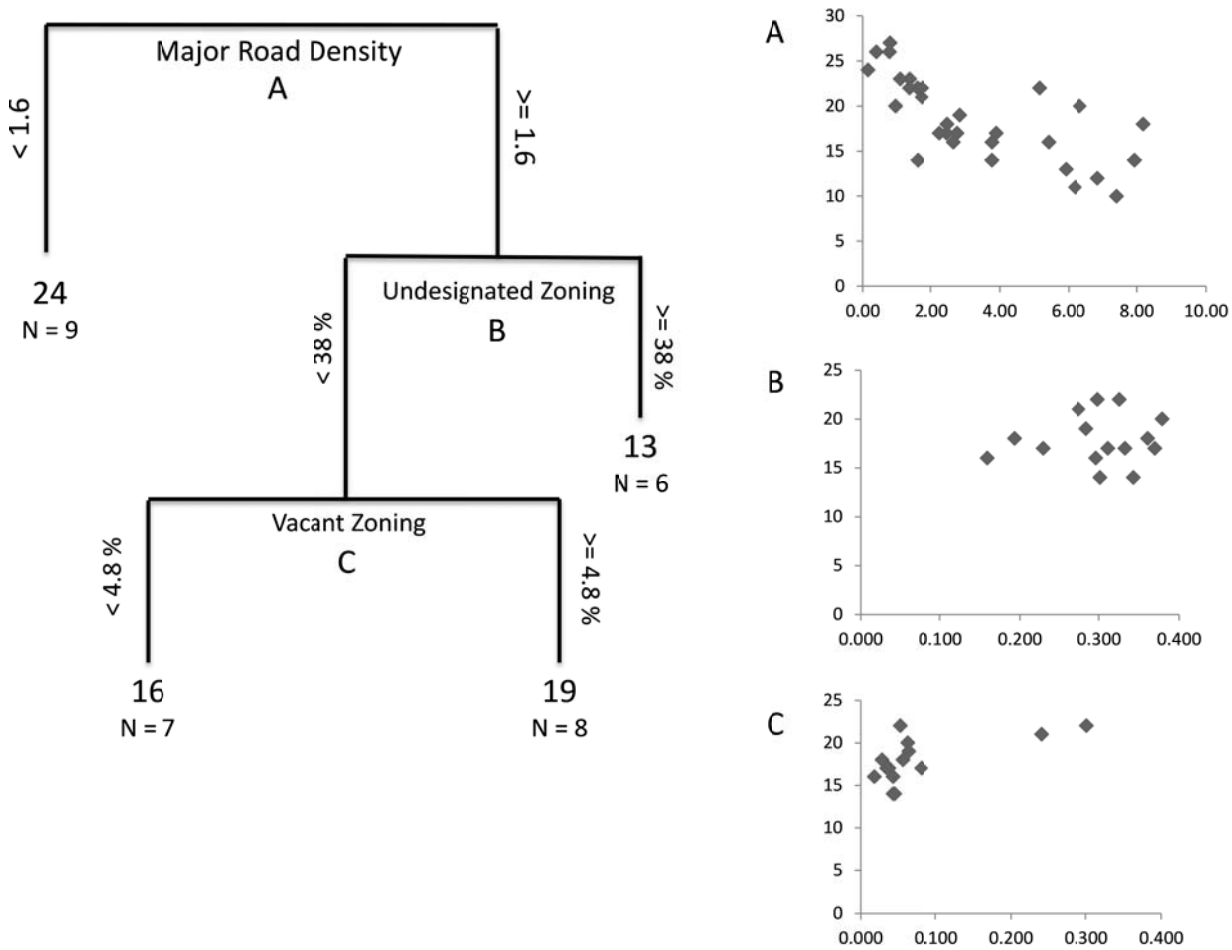

Figure 3: Regression tree analysis showing relationship between land use planning and native species richness along the urbanized portion of the Truckee River, Nevada, USA. Scatter plots show native richness (y) in relation to the splitting variable (listed above). Major road density and undesignated zoning were the top variables in describing avian richness and abundance. 76% of the total variance in native richness is explained by this regression tree.

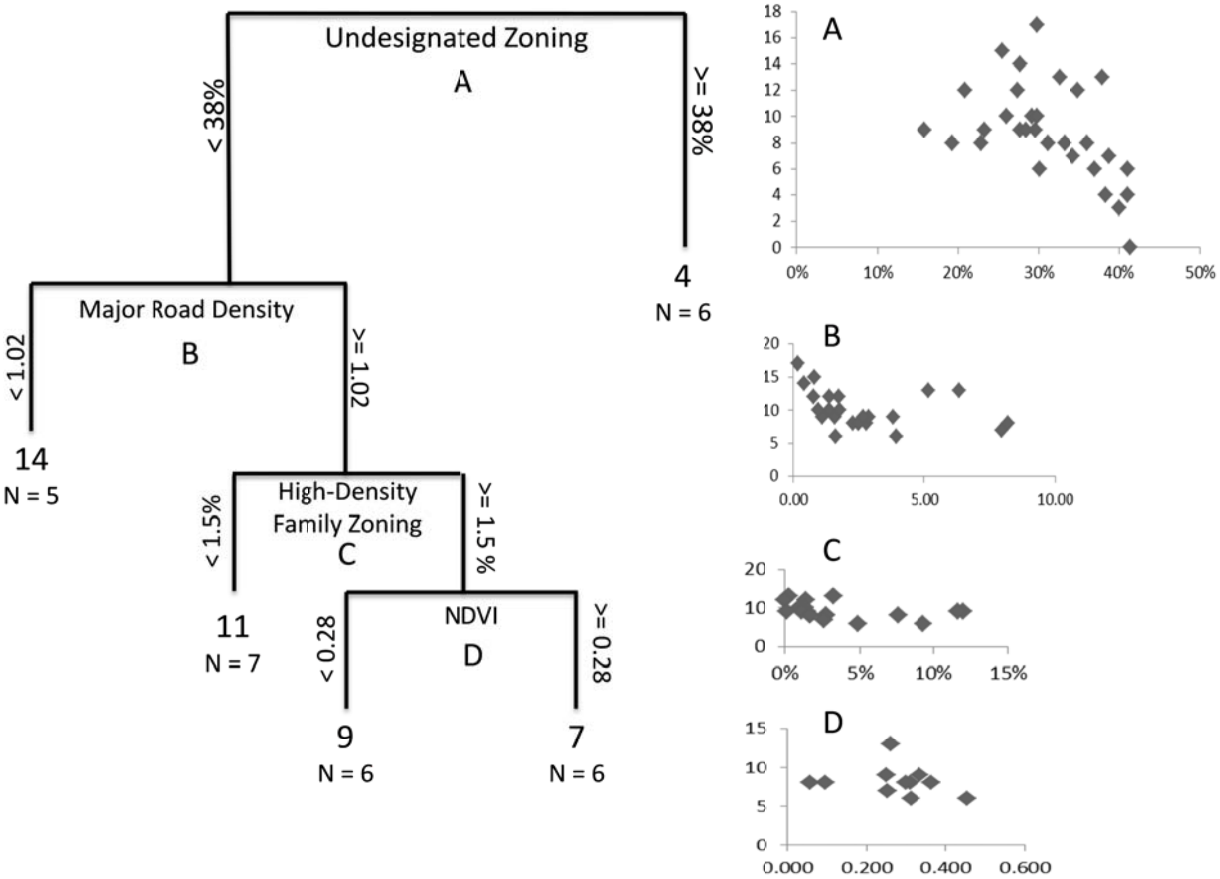

Figure 4: Regression tree showing nested relationship between land use planning and vegetation variables for riparian species abundance along the urbanized portion of the Truckee River, Nevada, USA. Riparian species richness had a very similar pattern, as did mid-canopy nesting species and Neotropical species richness and abundance. Again undesignated zoning and major road density split the data best, describing most of the variance seen in riparian species abundance. Total variance explained by this tree is 74%.

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Appendix 1: Individual variable correlations to bird species composition along the urbanized portion of the Truckee River, Nevada, USA. Variables are ordered in terms of their p-value (lowest to highest) and Mantel's r statistic (highest to lowest), and organized by variable type (vegetation vs. land use planning). NDVI had the highest single variable correlation to species composition, though several land use planning variables had significant correlations as well. The variables in bold were used to create a vegetation and land use planning dissimilarity matrix to compare as a whole to bird species composition.

Category	Variable	Mantel r	p-value
Vegetation Variables	**NDVI**	0.289	**0.002**
	NDVI @ 100m	0.147	**0.037**
	Exotic Tree Abundance	0.135	**0.044**
	Mean Tree Height	0.100	**0.099**
	Dead Tree Abundance	0.077	0.108
	% Grass	0.027	0.25
	% Shrubs	0.032	0.32
	% Barren	0.012	0.383
	Mean Tree Cover	0.023	0.383
	Willow Abundance	0.006	0.442
	Cottonwood Abundance	0.005	0.447
	Total Tree Abundance	-0.015	0.565
	Pine Abundance	-0.022	0.592
	Maximum Tree Height	-0.093	0.872
Land Use Planning Variables	**Multi-Family @ 500m**	0.219	**0.001**
	Major Road Density @ 500m	0.208	**0.003**
	Perimeter	0.209	**0.005**
	Open Space @ 1,000m	0.127	**0.027**
	Area	0.157	**0.028**
	Commercial @ 500m	0.154	**0.028**
	High Density Family @ 500m	0.071	**0.078**
	Commercial @ 100m	0.091	**0.094**
	Road Density @ 500m	0.110	0.11
	Multi-Family @ 1,000m	0.047	0.174
	Building Density @ 500m	0.061	0.177
	Multi-Family @ 100m	0.076	0.19
	Population Density @ 500m	0.047	0.193
	Undesignated Zoning @ 1,000m	0.067	0.201
	Commercial @ 1,000m	0.058	0.237
	Single-Family @ 500m	0.044	0.249
	Industrial @ 500m	0.045	0.254
	Land Values @ 100m	0.050	0.289
	Building Density @ 1,000m	0.041	0.293
	Undesignated Zoning @ 1500m	0.041	0.329
	High Density Family @ 1,000m	0.015	0.397
	Area-Perimeter Ratio	0.009	0.455
	Vacant @ 100m	0.000	0.462
	Open Space @ 500m	0.000	0.488
	Single-Family @ 100m	-0.010	0.52
	Open Space @ 100m	-0.011	0.522
	Land Values @ 500m	-0.025	0.565
	Single-Family @ 1,000m	-0.033	0.605
	Industrial @ 100m	-0.038	0.67
	Industrial @ 1,000m	-0.039	0.693
	Vacant @ 1000m	-0.047	0.727
	Building Size @ 500m	-0.059	0.747
	Vacant @ 500m	-0.065	0.83
	Undesignated @ 100m	-0.097	0.895
	Building Size @ 1000m	-0.101	0.9
	Population Density @ 1,000m	-0.140	0.959
	Agriculture @ 500m	-0.166	0.964
	High Density Family @ 100m	-0.179	0.965
	Agriculture @ 100m	-0.178	0.97
	Agriculture @ 1,000m	-0.194	0.972

Chapter 3: Scenario-based Conservation Planning for Urban Avian Diversity in a Growing Region of Nevada

E. Jamie Trammell, S. Bassett, M. Dolloff, D. Mouat

Abstract

Scenario modeling is a power tool for identifying uncertainty in future landscapes, especially in urban environments where land use policies are continually modified. Given that a primary objective of urban ecological work is to provide land use planners better management options, scenario modeling has been underutilized as a tool for examining urban conservation policies. We constructed three scenarios that assess 1) a continuation of the trend (business as usual), 2) a regional open space plan and 3) an avian habitat-focused futures and the potential impacts of future growth in the Truckee Meadows, Nevada, USA, on avian diversity. The Trend scenario exhibits the largest impact on all levels of avian habitat, while the avian habitat focused scenario protects the most avian habitat overall. However, the open space plan scenario was also effective at protecting most of the avian habitat in the region. This research highlights the ability of local open space plans to be modified to protect urban biodiversity using local research, and the ability to test potential urban conservation policies in the future under different growth scenarios.

Keywords: alternative futures, avian conservation, land use planning, open space, urban ecology, urban growth

Introduction

The use of scenario modeling has become increasingly popular for comparing different land-use policies (Shearer et al. 2006, Langpap and Wu 2008, Brambilla et al. 2010, Bryan et al. 2011), species management alternatives (Peterson et al. 2003, Forbis et al. 2006, Gude et al. 2007, Mortberg et al. 2007, Watts et al. 2010) and assessing climate change (Hester and Harrison 2002, Pachauri and Reisinger 2007, Hansen 2010). In a special feature of *Ecology and Society,* Helming and Perez-Soba (2011) pointed out that scenario modeling of alternative plausible futures are a critical tool for identifying uncertainties that may shape the future of a landscape. The identification of uncertainty is quite attractive to ecologists developing predictive models (Carpenter 2002), which has encouraged an increase in ecological and conservation biology scenario analyses (Clark et al. 2001, Peterson et al. 2003, Biggs et al. 2007, Jetz et al. 2007). However, the application of scenario modeling to urban ecosystems has been limited, despite the direct link between land use plans and urban ecology (Hepinstall et al. 2008). Urban environments can be structured to follow specific policies (i.e. land use plans) that encourage urban biodiversity (Marzluff and Rodewald 2008, Gordon et al. 2009). Since biological resources are likely to change in the future, especially as cities continue to grow, scenario modeling can be an important tool for exploring uncertainty related to urban growth and biodiversity policies into the future.

Specifically, scenario analysis can be used to examine the effectiveness of open (green) space plans in protecting urban biodiversity in the future. While open space has been found to be an important predictor in urban ecological studies (Sandstrom et al. 2006, Ortega-Alvarez and MacGregor-Fors 2009), there are few examples that specifically examine the effectiveness of open space plans in protecting urban biodiversity. This is surprising, given that one of the primary goals of urban ecological studies is to inform land use planning (Shochat et al. 2006). Furthermore, very few urban ecology principles have been tested in a planning and policy framework. Many urban ecological studies have documented the importance of native vegetation (Germaine et al. 1998), local and landscape habitat connectivity (Oneal and Rotenberry 2009), and minimization of the built environment (i.e. roads and other impervious surface) (Mason et al. 2007, Ryder et al. 2010) to urban biota, but few have provided specific planning recommendations to accomplish their goals (McIntyre et al. 2000, Chace and Walsh 2006). Furthermore, the need to test these policies under different growth alternatives is essential to ensure they stay robust under future urban change.

This study aims to bridge some of the disconnect between urban ecologists and urban planners by using local empirical research on avian diversity to develop land use policies, and compare these policies to three different development scenarios for the Truckee Meadows, Nevada, USA. Our first objective in this study was to quantify the potential impacts to avian habitat under a business-as-usual scenario (i.e. continuing with the current trend) compared to an avian-conservation focused scenario. Our second objective was to compare the impacts of future development on avian diversity under the avian-conservation scenario compared to a locally developed open space plan administered by the county government.

Given the likely continued expansion of urban environments, the ability to identify potential unforeseen impacts to biodiversity is critically important (Clark et al. 2001). We expect that modeling bird diversity under different scenarios will highlight the effectiveness of current land use policies in protecting important bird habitat. We also expect modeling bird diversity under multiple scenarios will yield more robust policies that account for future urban growth and help promote an adaptive management framework for managing urban biodiversity.

Methods

Study Area

The Truckee Meadows (Figure 1), including Reno and Sparks, Nevada, is located at the western edge of the Great Basin desert where sagebrush-steppe communities dominate most of the landscape, and riparian areas represent the most productive habitats for a variety of biodiversity (Rood et al. 2003). Like other western cities, Reno and Sparks have grown significantly over the past 30 years (Hardcastle 2010a), despite the current population plateau. Population growth in the region has averaged 2.6% annually, or about 28% per decade, from 1980 to present, and had an estimated population of 398,000 in 2010 (Hardcastle 2010a). The Truckee River is the primary source of municipal water for the Truckee Meadows, as well as an important draw for recreation (Cobourn 1999). The nexus of the Truckee River and the cities of Reno and Sparks has created a challenge for regional planners who want to promote growth, but need to protect the region's water supply, recreational opportunities, and important habitat for biodiversity. Likewise, fluctuations in economic and population growth makes the Truckee Meadows an ideal place to study urban growth uncertainty as it relates to regional biodiversity.

Population Forecasts

Three population forecasts were used to capture the uncertainty of population growth in the region. Regional population forecasts were only available through 2030, so population growth to 2050 was extrapolated using least-squares linear regression. The highest forecast, which predicts 333,100 new residents will move into the study area by 2050, was taken from the state demographers high population forecast (Hardcastle 2010b). A medium population forecast estimates up to 192,890 new people moving to the region according to a local water authority's future forecast (TMWA 2010). The third population forecast uses the state demographers low forecast and only predicts 34,730 new people by 2050 (Hardcastle 2010b). We modeled growth to the year 2050 to be consistent with other scenario research in the region (Dolloff 2011), and to give a longer term perspective on growth in the region, especially given the variability in population forecasts.

Scenarios

Three plausible scenarios for growth in the region were identified to highlight the alternative land use impacts on avian diversity in the Truckee Meadows. The goal of this study is to assess the impact different land use scenarios have on avian resources in the Truckee Meadows, so scenarios focus primarily on alternative land use policies instead of other socioeconomic policies (Jantz et al. 2004, Santelmann et al. 2004, Song 2006, Verburg et al. 2006). While these scenarios do not encompass all the possible growth scenarios for the region, they are designed to represent various policy options for the Truckee Meadows in terms of open space and urban avian habitat conservation.

Trend Growth Scenario

Increasingly, the trend for development in the Truckee Meadows has been focused around master planned areas, often outside the urban core. This is assumed to continue in the trend scenario, with much of the future growth occurring in larger parcels around the urban perimeter. Urban sprawl continues, as the number of people per household stays constant at 2.6, and the average residential lot size (including all associated infrastructure) remains 0.2 hectares (Dolloff 2011). No new development restrictions are implemented under this scenario for fear of hindering economic growth.

Open Space Scenario

The emphasis in this scenario is on implementing the biodiversity goals set in the Washoe County Open Space Plan (Washoe County 2008). High biodiversity resource areas identified in the open space plan (Figure 2) are protected throughout the Truckee Meadows, as is the Truckee

River Flood Plan (TRFP 2010). The Washoe County Open Space Plan is nationally recognized for its effort to conserve ecosystem services as well as critical habitat and recreation opportunities. The TRFP was designed to reduce catastrophic floods in the Truckee Meadows through increased parks and terraces along the Truckee River. Lands available for development are significantly reduced, causing residential density to increase to an average of 0.144 hectares per residential lot (a 30% reduction) for the high population forecast, and 0.175 hectares (15% reduction) for the medium and low population forecasts. Number of people per household is held constant at 2.6.

Avian Conservation Scenario

The Avian Conservation scenario focuses on protecting urban habitats for birds. Empirical avian habitat relationships (Trammell et al. *in press*, Trammell and Bassett, *in review*) are used to justify the protection of all remnant riparian habitats that are not close to major roads, and all wetlands are protected with a 50m buffer. No new roads are allowed along the Truckee River, and tree plantings are encouraged within a kilometer of the Truckee River in open spaces and parks to extend the riparian corridor. Same as the Open Space scenario, residential lot sizes are reduced under the high population forecast. Although this results in an increase in multifamily zoning, and local research has found that most native species respond negatively to higher density residential development, no multifamily zoning is allowed within 1km of the Truckee River (Trammell and Bassett *in review*). In the low population forecast, the Truckee River floodplain through Reno and Sparks is redeveloped into parks with cottonwood trees being planted and connectivity to other wetlands emphasized. Housing density for all three population forecasts is the same as the Open Space scenario, as is the number of people per household.

Urban Growth Model

Description

We used a simple cellular-automata model to spatially allocate future growth according to environmental characteristics and land use policies (Barredo et al. 2003). This specific model was developed to assess growth potential throughout the southwestern U.S. based on exclusion and attraction zones for use in a variety of future impact analyses (see Kahyaoglu-Koracin et al. 2009 for an example). We chose a simple model for repeatability/transferability, and although the model does not output specific land use allocations, the level of detail was sufficient for an impact analysis on regional avian habitat. We chose a spatial resolution of 20m x 20m because it represents the average residential parcel size (calculated from parcel database, see below) allowing more accurate modeling of urban infill.

Four datasets are required for the urban growth model: existing urban, growth zones, buildable lands, and growth model extent. Growth was only modeled on buildable lands that were generated by taking the inverse of a set of basic growth exclusions, plus exclusions associated with the specific scenario (Table 1). Proximity to existing urbanization is the primary deterministic factor for the urban growth model, which is calculated by generating a Euclidean distance raster from the existing urban layer. Existing urban was generated using a land owner parcel database acquired from the Washoe County data warehouse (www.co.washoe.nv.us/gis/datawarehouse.htm). Growth zones partition the new growth into meaningful regions, which were created by merging city, neighborhood, and master planned community boundaries into 15 growth areas (Figure 1). Growth zones can be used as regional attractors of growth by allocating a higher percentage of the forecasted growth, or can be used as exclusions by removing any future growth allocations, and generally varied by scenario and population forecast. Model extent was taken from the current area of service (study area boundary), and although it includes Bureau of Land Management lands (federally owned and managed), no growth was allowed on these lands in any of these scenarios. For scenarios that explore the possibility of public land transfers, please see Dolloff (2011).

While the growth model we used does allow for growth to be modeled over several iterations, buildable lands were abundant enough to model all the forecasted growth for each scenario as a single 40 year time step (i.e. zone allocations did not need to be modified within the 40 year interval). Initial population for each scenario was the same (398,000), but growth rate varied based on the three population forecasts. Growth rate was calculated by dividing the amount of population growth forecasted by the initial population for the time period modeled.

Calibration

Calibration of urban growth models can be particularly difficult depending upon their spatial resolution and output format (Jantz and Goetz 2005). We calibrated our model to historic urban growth patterns (Barredo et al. 2003, Solecki and Oliveri 2004) from 1979-2009. Historic urban growth was modeled using a parcel tracking system developed by the local water authority (TMWA 2010, Dolloff 2011). Growth rates, along with average lot size, ratio of single family zoning to multifamily zoning, and average commercial, park and road development per person were all calculated using the historical parcel database. Model calibration subset this data into zones so growth could be calibrated zone by zone.

Precise model accuracy is not likely in most cellular-automata models (Jantz and Goetz 2005), so model fit was assessed in multiple ways. Visual assessment was used for the calibration runs (Sante et al. 2010), while exact and neighborhood accuracy (Hansen 2010) was calculated using model outputs in ArcGIS 10 (Environmental Systems Research Institute). Exact accuracy was assessed by overlaying the modeled growth with actual growth (generated from the parcel database), while neighborhood accuracy was calculated by expanding both urban grids (modeled and actual) by one and three cells and then overlaying the two outputs. The exact accuracy indicates model precision, while the neighborhood accuracy captures the growth pattern accuracy. Additional information about the model and calibration methods can be found in Dolloff (2011).

Avian Habitat Impact Assessment

Impacts to avian habitat were calculated using a habitat priority model based on target species groups (Table 2, Figure 2). Habitat priority was ranked based on empirical data from local avian ecology studies (Trammell et al. *in press*, Trammell and Bassett *in review*), with the priority being on riparian-dependent and native species. Upwards of 90% of the natural riparian habitat in the arid western U.S. has disappeared over the last 100 years, making riparian-dependent species a high conservation priority (Patten 1998, Rich 2002). Using point count data, Trammell and Bassett (*in review*) found that riparian species were identified only in habitats away from major roads (and their associated land clearings) and away from high-density residential zoning. Overall native species diversity in the Truckee Meadows is correlated to distance from the Truckee River (closer = higher richness), though roads need to be at least 250m away (Trammell et al. *in press*). Native species also prefer habitats with taller trees away from large buildings, and prefer patches of habitat that have native vegetation and connect with the natural landscape (Trammell and Bassett *in review*). Vacant lots can provide habitat to native species that can adapt to urbanization, as does a diversity of vegetation in open space and parks. Thus, urban growth impacts are presented in terms of avian habitat priority, defined by target communities.

In addition to the avian habitat priority impacts, we also assessed the impact of future growth on potential regional and local reserves. Potential regional bird reserves were identified by extracting patches of riparian habitat that were over 42 hectares in size (Donnelly and Marzluff 2004) within the study area, as they are likely important for regional avian diversity. Local reserves were identified by extracting smaller patches (1-42 hectares) of native and riparian habitat, as they may provide critical habitat for migratory and urban riparian birds (Atchison and Rodewald 2006, Pennington et al. 2008).

Results

Model Calibration

The urban footprint in the Truckee Meadows grew from 10,800 hectares in 1979 to just under 28,000 hectares in 2009, which represents a 159% increase in urban area. Classification precision (exact cell accuracy) was moderate, but the model proved quite good at capturing the pattern of growth. Model precision was 56%, while pattern accuracy within one cell (± 60m) was 66%, and within three cells (± 180m) was 75%. Given the spatial resolution (20m) and temporal resolution (30 years), the cellular automata model performed well.

Urban Growth Allocations

In all of the scenarios, nearly all of the buildable land was developed under the high population forecasts. On average, the high population forecasts developed 90% of the available land, the medium population forecasts developed about 61%, and the low forecast developed about 11% of the available land. Growth rate for the high population forecasts was calculated at 83% for the 40 year time period, 48% for the medium forecast, and 8% for the low forecast. As expected, the high population trend scenario developed the most amount of land (26,315 hectares), while the open space and avian futures developed the least amount of land under the low population forecast (just 2,310 hectares). Development patterns varied according to the allocations in the different zones, and depended upon the available buildable land and amount needed to satisfy the population increase. A table of all the allocations by zone can be found in Appendix 1, while Figure 3 depicts the alternative growth patterns in relation to buildable lands by scenario.

The Trend scenario represents relaxed land use restrictions, resulting in unilateral growth throughout the Truckee Meadows. All currently undeveloped lands along the Truckee River are developed, as are wetlands and agriculture on the eastern and southern portions of the study area.

Larger lot sizes result in more land being developed than any other scenario. The Open Space scenario limits growth significantly more than the Trend, but with a higher average residential density, is still able to accommodate the projected growth in the study area. Sensitive species, along with wildlife corridors, significantly limit growth potential in west Reno. Development is shifted north and east, increasing sprawl into satellite communities. The Avian future has a very similar pattern to the Open Space scenario, although no growth is allowed along the Truckee River corridor. Less development occurs in the satellite communities far to the north of the study area, primarily because fewer restrictions were placed on development around the perimeter and in the suburbs.

Impacts on Avian Habitat

Impacts to avian habitat varied by scenario and population forecast, but generally followed the growth allocations (Figure 4). The Trend scenario had the largest impact on bird habitat across the board. Except for riparian habitat, Open Space and Avian Conservation scenarios had equal impacts on avian habitat. The Avian Conservation scenario had a slightly higher impact on urban adaptor (medium priority) and urban bird habitat (lowest priority) than the Open Space scenario, though it was minimal. Similarly, the Trend scenario develops far more of the local reserves, and fragments many of the regional reserves (Table 3). The Open Space scenario results in some lost local and regional reserves, while the Avian Conservation doesn’t develop any of the reserves.

Discussion

Future Impacts to Avian Diversity

As expected, the Trend scenario led to the greatest loss of avian habitat. As is true in most arid cities, development typically initiates immediately near a permanent water resource (Patten 1998), and this has been the case for the Truckee Meadows. Under the Trend scenario we expect to see continued growth along the Truckee River, primarily based on its proximity to existing development and infrastructure, and due to its aesthetic appeal for residential developments. Although there are flood restrictions on growth immediately near the river, the regional growth plan encourages growth along the river to promote more transportation oriented developments. Without specific land use restrictions, this may result in substantial loss of riparian and native bird habitat.

Conversely, the Avian Conservation scenario demonstrates that policies can be implemented to protect important riparian habitat, without compromising future development. It also appears that although the focus of the Avian Conservation scenario was on riparian habitat, habitat for other native species was not significantly impacted. This could suggest that riparian focused conservation, along with higher density development, may be an effective way to protect avian habitat in the region.

The most interesting result came from comparing the Open Space scenario to the Avian Conservation scenario. First, the Open Space scenario was more restrictive than the Avian Conservation scenario, primarily because the county open space plan was designed for multiple taxon and protection of ecosystem services. While this did result in slightly more sprawl, the scenario developed very little avian habitat, especially when compared to the Trend scenario. Although the Avian Conservation scenario did a better job at protecting riparian species habitat (highest priority), the Open Space scenario seems to do a better job protecting a variety of habitats, which is important for beta and gamma avian diversity, as well as other taxon. This is especially important since focusing on one specific taxa or groups within taxa often leads to unintended consequences for other non-target species (Soule et al. 2005).

Another important finding comes from examining the potential trade-offs and habitat contradictions. The densification of future urban development was required by both the Open Space and Avian Conservation scenarios with the high population forecast. However, higher density housing is negatively correlated to many species in the urban environment (Trammell and Bassett *in review*). Others have discussed similar tradeoffs between highly concentrated development vs. clustered vs. sprawled development (Lenth et al. 2006, Hostetler and Drake 2009, Gagne and Fahrig 2010), with the outcome largely depending upon the species or groups of interest. Comparison of these types of development is crucial in future studies, and ecologically-based scenarios can help us better understand the tradeoffs that must be made with policies in order to accomplish different objectives (i.e. climate change mitigation, biodiversity, urban cooling, walkability, etc.).

Conservation Opportunities

Given the uncertainty in population, policies that are flexible to varying levels of potential growth are needed. By modeling a low growth scenario, we see the opportunity for novel conservation planning. Redeveloping parts of the downtown areas could be used to mitigate potential losses of habitat patches elsewhere, and could potentially increase bird diversity within the urban core, or increase connectivity between existing riparian reserves. The creation of two whitewater parks in Reno (in 2005) and Sparks (in 2009) are excellent examples of how this type of conservation planning is within reach.

The opportunity for collaboration between shared interests is clear. Both the Washoe County open space plan and the Truckee River Flood Project have identified riparian protection as a goal. Likewise, bird conservation groups like the Audubon Society or larger conservation organizations like The Nature Conservancy and World Wildlife Fund may also be interested in these urban riparian areas as it relates to regional biodiversity. Modeling these potential impacts highlights opportunities for stakeholders with similar goals to collaborate on policies that protect common interests. The role of land use planning in conserving avian habitat is also clear. Small modifications to the open space plan could ensure that riparian birds, in addition to other native species, will have adequate protection under future urban development. A focus on protecting existing riparian reserves, especially those above 42 ha in area would be an excellent first step.

Future Research

One limitation of this study was the inability to model future roads, especially freeways, highways and arterials. This land use has the largest impact on the viability of habitat for riparian and native birds alike, yet the future plans for major roads are not specific enough to model them effectively. Thus, while we can model the impacts of future growth and zoning on avian diversity, we are likely underestimating the impact that may occur as a result of the urban growth. Similarly, the inability to model specific land uses into the future also limits our ability to forecast impacts on avian diversity. Trammell and Bassett (*in review*) found a strong correlation between specific land uses and avian diversity. For a more comprehensive picture of urban bird diversity in the future, specific future land use needs to be modeled as well.

Similarly, this study proposes riparian birds are the highest conservation priority, when other stakeholders may think differently. Beta and gamma diversity were minimally accounted for in this analysis, so research into the habitat needs and associated land use preferences for wetland birds and waterfowl, along with a more complete census of birds that completely avoid urbanization, would help in understanding the comprehensive impacts of growth on regional avifauna.

Although no other impacts were modeled as part of this analysis, the scenarios presented are likely to impact important socioeconomic and biophysical features of the Truckee Meadows in different and important ways. For example, quantifying how ecosystem services are impacted by the three scenarios could help refine the open space plan to ensure those services are protected in the future. Similar to urban ecology, weighting alternative land use policies and their impacts on current and future ecosystem services is a necessary direction to ensure sustainable urban growth (Rodriguez et al. 2006, Walz et al. 2007, Nelson et al. 2010).

Finally, combining urban ecosystem scenarios with climate change scenarios would provide a more comprehensive picture of landscape change. Many studies have begun downscaling the IPCC scenarios to local/region urban environments (Carter et al. 2004, Solecki and Oliveri 2004, Dolloff 2011) and assessing the likely impacts of those global scenarios on local social environments. Combining these forecasts with land use planning scenarios, especially those focused on habitat protection and ecosystem services, could yield a powerful tool for identifying future landscape change. Additionally, this combination may help identify opportunities for additional habitat reserves, as urban environments may become refuges for certain species under climate change (Kadlec et al. 2008).

Conclusion

Forecasting landscape change is a difficult yet necessary challenge for urban and conservation planners alike (Sutherland et al. 2009). Scenario analysis can help by exploring alternative scenarios of change, and quantifying the impacts on resources of interest (Peterson et al. 2003). Alternative scenarios can show how region might grow, given different assumptions and policies, and help to highlight overlapping, or conflicting, policy goals and interests, as was demonstrated here. It appears that the current open space plan does a decent job at protecting avian habitat under different growth scenarios. Additionally, the conflict between future urban development and avian conservation seems to be reduced when taken in light of potential policies that accommodate both. This ability to develop consensus in land use planning is important given the uncertainty in both regional growth and future biodiversity conservation.

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	Trend Scenario	Open Space Scenario	Avian Conservation Scenario
Scenario Narrative	No new development restrictions	Protect current and future open space	Protect all current and future open space
	Prime lands developed	Protect ecosystem services like wetlands	Protect wetlands w/50m buffer
		Protect flood control areas	Protect flood control areas
		Protect high biodiversity habitats	Protect all habitats within 1km of Truckee River
Translated Exclusions	Federal and other protected lands	Federal and other protected lands	Federal and other protected lands
	Existing urbanization	Existing urbanization	Existing urbanization
	Existing roads	Existing roads	Existing roads
	Existing railroads	Existing railroads	Existing railroads
	Slopes > 20%	Slopes > 20%	Slopes > 20%
	Water bodies	Water bodies	Water bodies
		UNR Farms	UNR Farms
		Wetlands	Wetlands
		Current Open Space	Current Open Space
		Zoned Open Space	Zoned Open Space
		Flood Control Areas	Flood Control Areas
		High Biodiversity Areas/Corridors	50m buffer around wetlands
			Non-major road habitat w/in 1km of Truckee

Table 1: Key scenario narrative descriptions, along with corresponding exclusion layers for scenarios in the Truckee Meadows, NV, USA. The Open Space scenario results in the most land restrictions, while the Trend scenario has very few limitations. The Avian Conservation scenario protects riparian and large patches of native habitats to maximize avian diversity.

Avian Habitat Priority	Habitat Description	Target Species Groups
Highest	Existing riparian and wetlands habitat away from major roads	Riparian species (Rich 2002), insectivores, species that require close water resources
High	Large patches of native sagebrush/rangeland habitats with low road density (< 1 major road w/in 1km)	Most non-riparian native species, especially those from the sagebrush communities
Medium	Remnant habitats surrounded by development with medium road density (< 1.5 major roads w/in 1km)	Native species that are found in higher abundances in the urban environment
Low	Any remaining habitats with high road density, little remnant vegetation, and high density family (> 5 units/parcel) zoning	Exotic species, urban obligate species

Table 2: Avian habitat priority model developed using empirical data collected around Reno and the Truckee River, NV, USA. Habitat priority impacts were calculated based on potential future growth under different scenarios for the Truckee Meadows.

Scenario	Trend Growth			Open Space			Avian Conservation		
Population Forecast	High	Medium	Low	High	Medium	Low	High	Medium	Low
Riparian Reserves	543 (10)	537 (10)	153 (8)	167 (9)	167 (9)	79 (7)	-	-	-
Small Reserves	86 (5)	87 (4)	34 (5)	31 (3)	31 (3)	20 (1)	-	-	-

Table 3: Summary of impacts to potential avian habitat reserves under three scenarios of urban development in the Truckee Meadows, NV, USA. Impacts are presented as hectares lost and number of reserves (in parentheses) completely lost to development. The trend scenario develops the most habitat reserves, while the Open Space scenario develops substantially less riparian and small reserves. Specific policies prohibit any development of reserves within the Avian Conservation scenario.

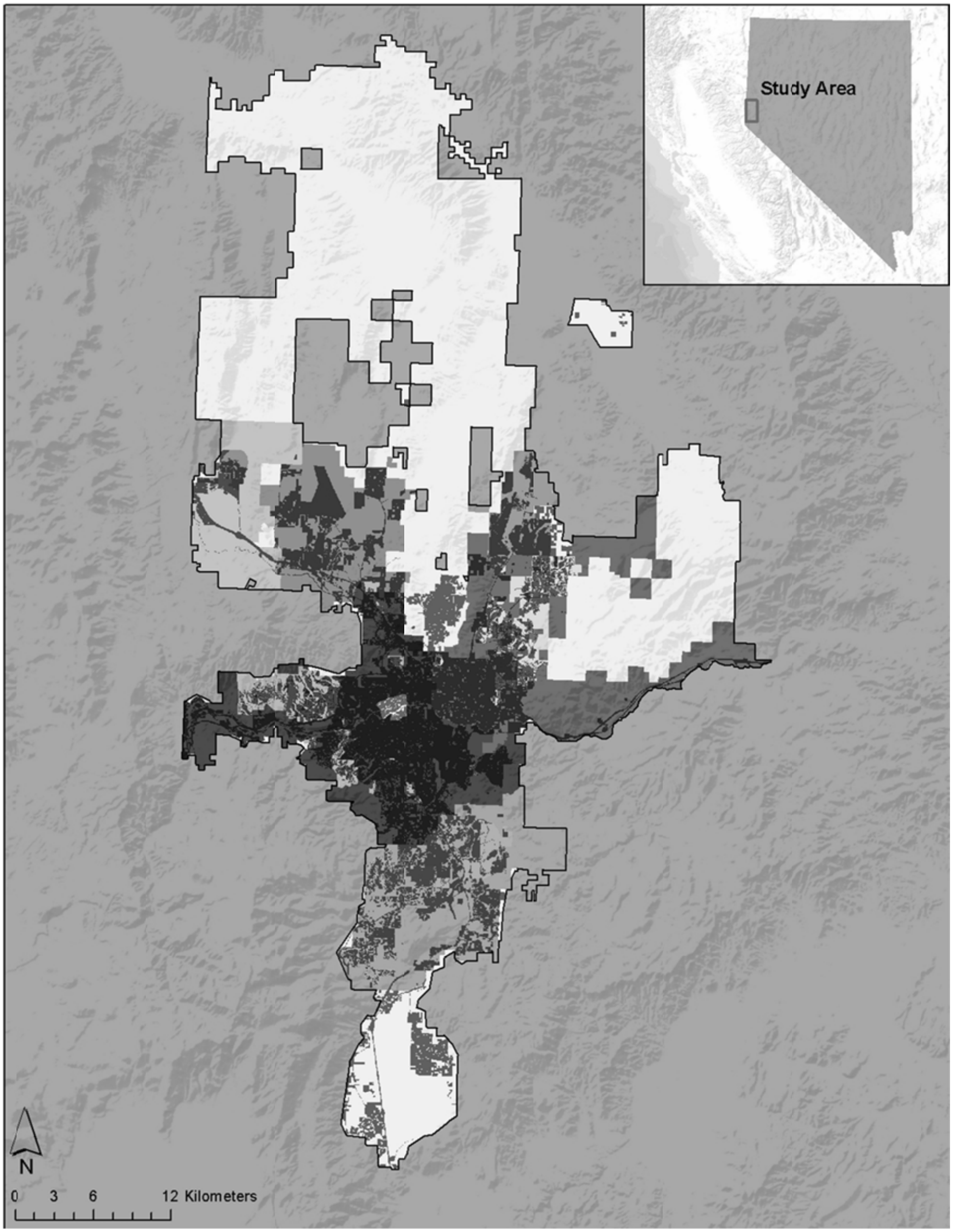


Figure 1: Growth zones and urban footprint (in 2009) used in the calibration and modeling of future growth in the Truckee Meadows, NV, USA. The names of the zones are included in Appendix 1.

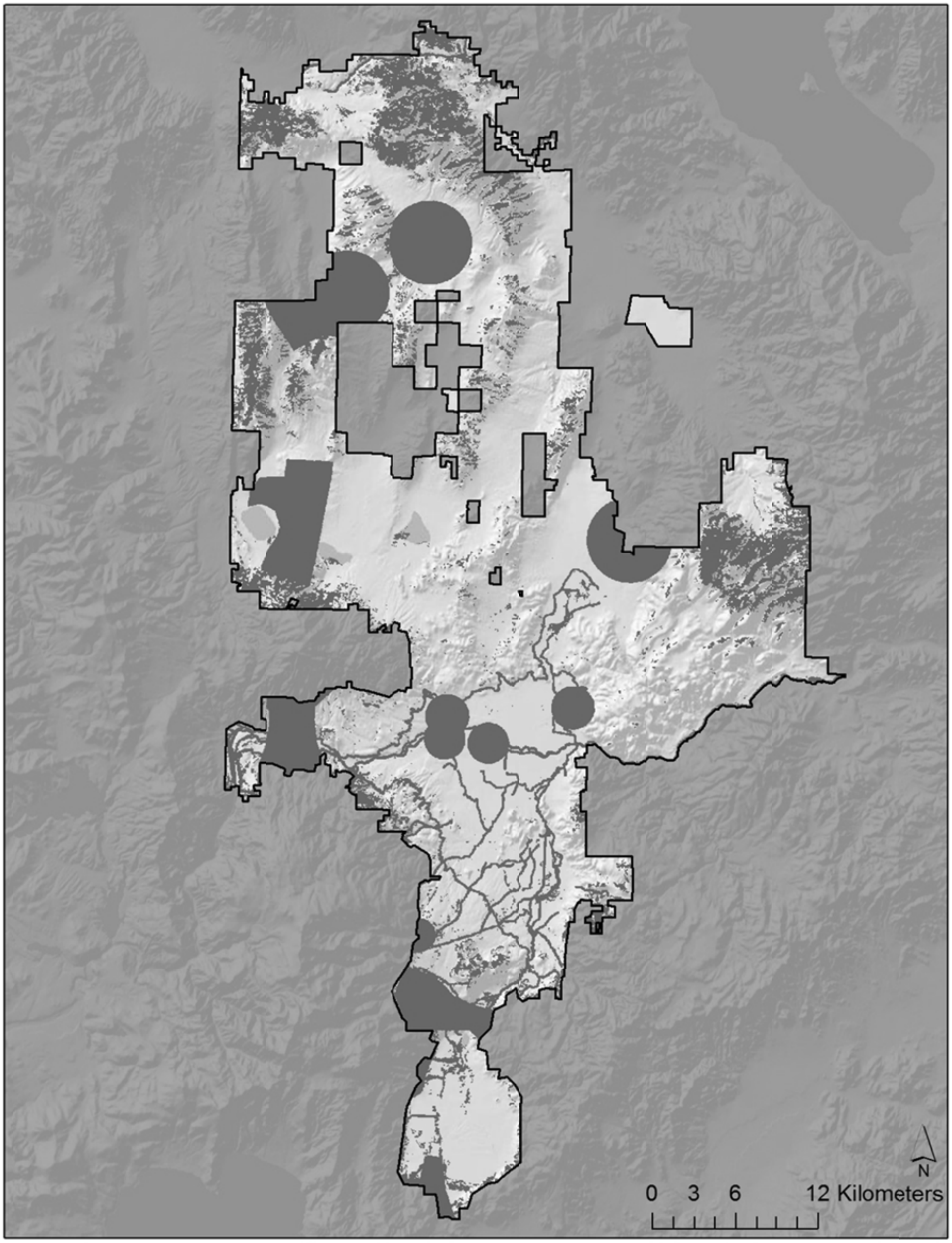


Figure 2: High biodiversity resources identified in the regional (Washoe County) open space plan for the Truckee Meadows, NV. High biodiversity habitats include riparian (thin linear features), key vegetation communities (Pinyon-Juniper woodland patches), sensitive species habitats (large circles) and important habitat corridors (large blocks). Growth was excluded in these areas under the Open Space Scenario, resulting in less buildable lands than the Avian Conservation Scenario.

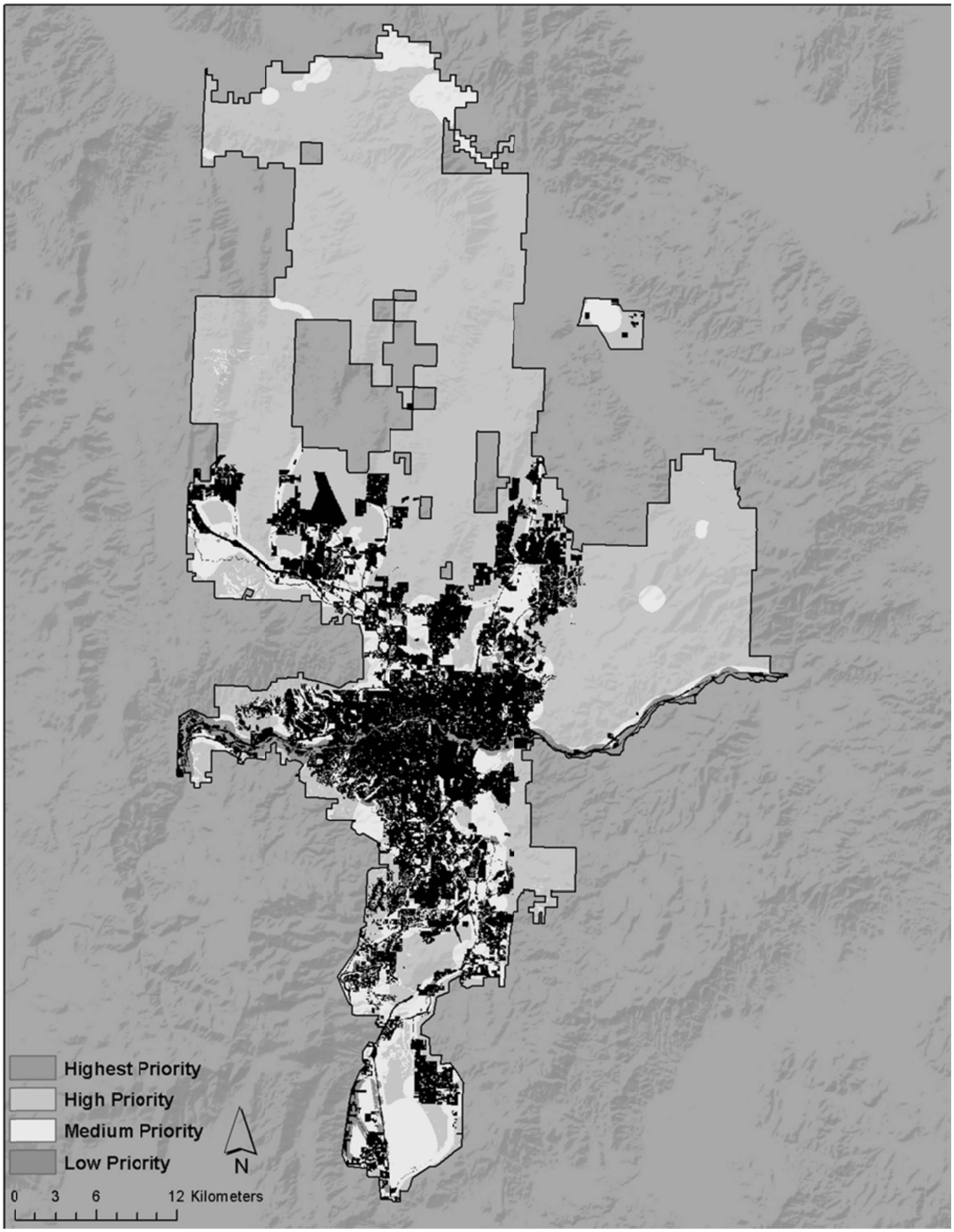


Figure 3: Avian habitat priority model for the Truckee Meadows, NV, USA. Black indicates the urban footprint as of 2009. Habitat priority was used to measure the effectiveness of avian-focused urban planning compared to trend growth and the current open space plan.

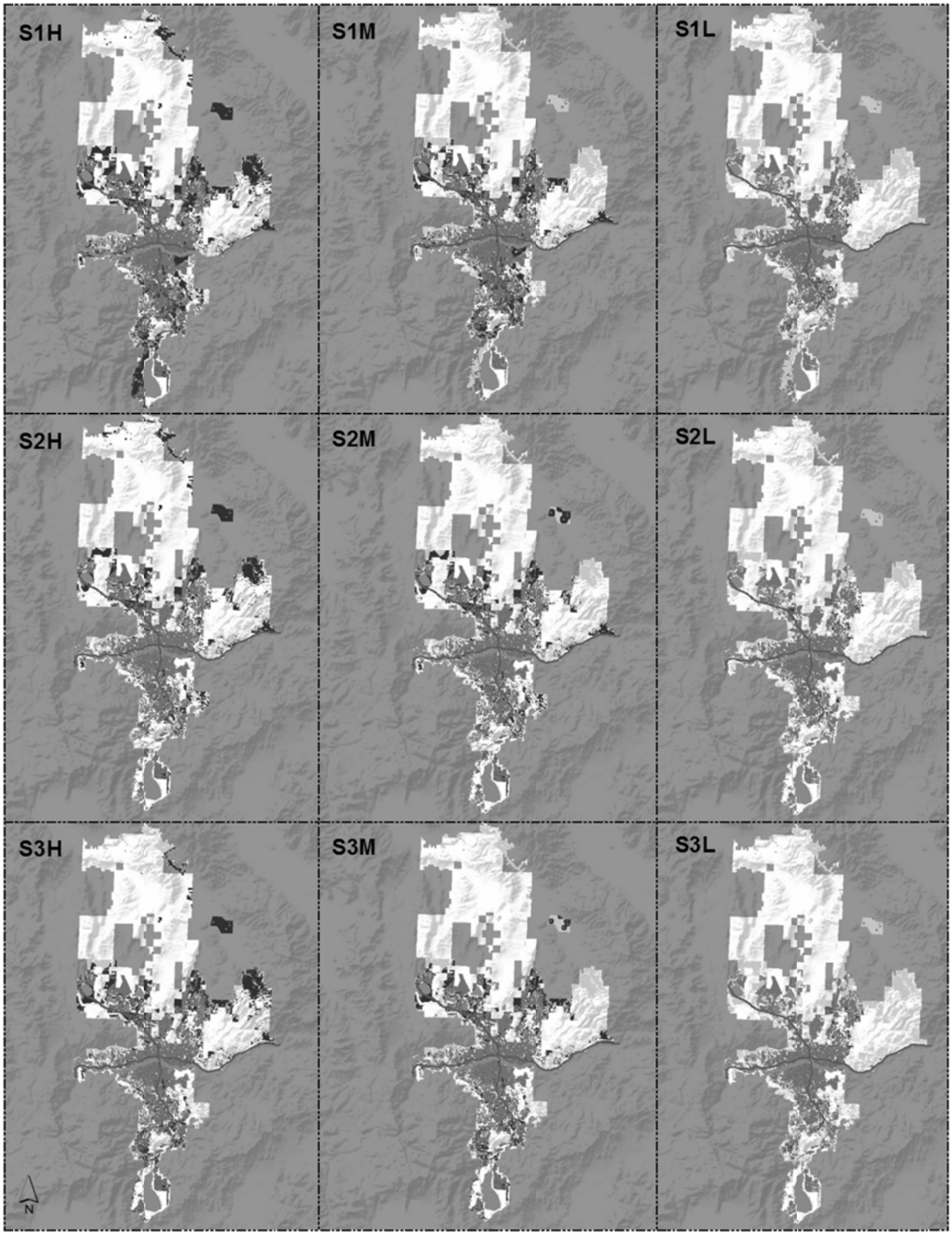
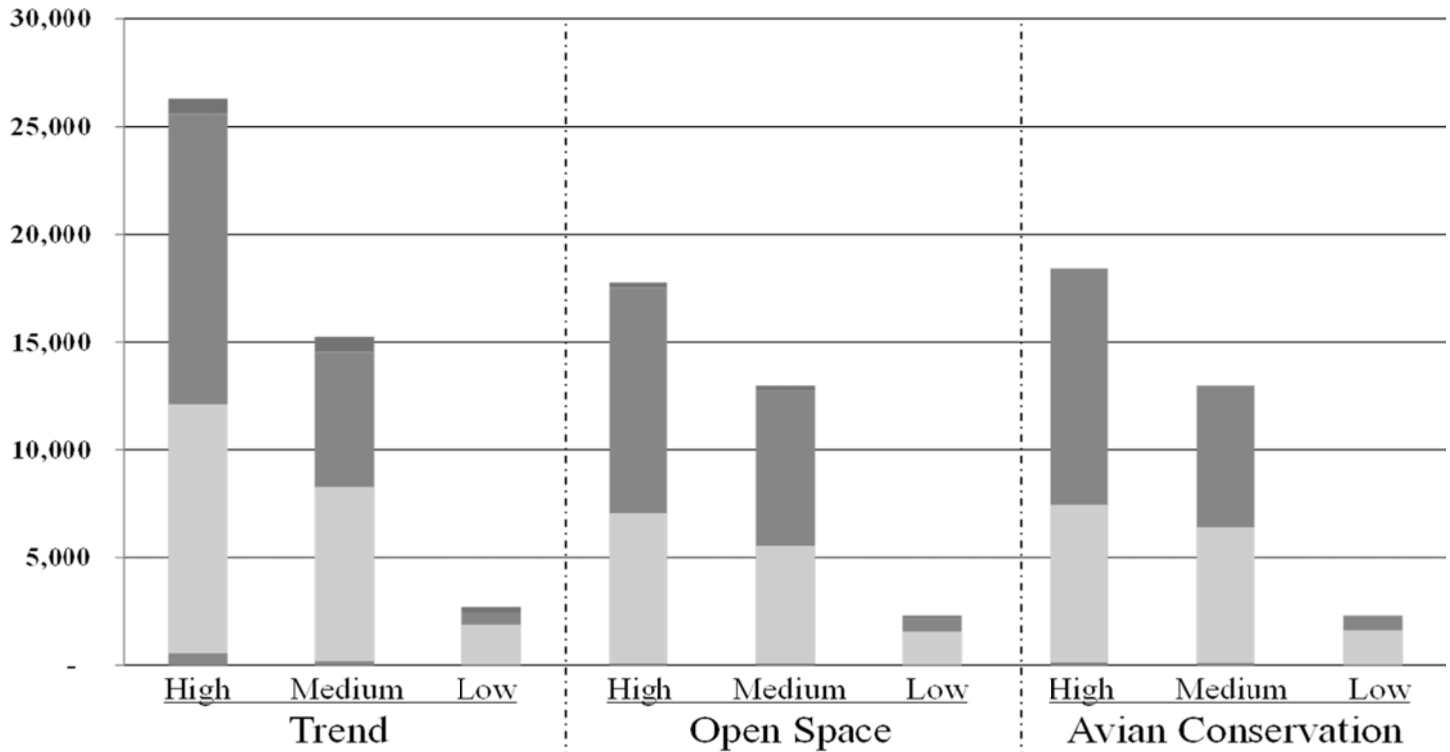


Figure 4: Alternative growth patterns for the Truckee Meadows, NV, USA. S1 = Trend scenario, S2 = Open Space scenario, S3 = Avian Conservation scenario; H = high population forecast (~ 333k new residents), M = medium population forecast (~192k new residents), L = low population forecast (~34k new residents). Medium grey is urban development in 2009, darker grey is modeled urban development in 2050. Light grey is buildable lands, defined differently for each scenario. Scale is 1:1,000,000.



	Trend High	Trend Medium	Trend Low	Open Space High	Open Space Medium	Open Space Low	Avian Conservation High	Avian Conservation Medium	Avian Conservation Low
Riparian	31%	31%	11%	10%	10%	6%	0%	0%	0%
Native	14%	6%	1%	11%	7%	1%	11%	7%	1%
Urban Adaptors	45%	32%	7%	27%	21%	6%	29%	25%	6%
Urban	86%	29%	4%	13%	13%	2%	19%	18%	2%

Figure 5: Potential impacts to avian habitat under three development scenarios for the Truckee Meadows, Nevada, USA. The graph depicts total hectares of habitat loss in each of the habitat priority categories; while the table presents the percentage (of the total available habitat) that would be lost. The Trend scenario results in the most habitat loss across all the categories, while the Open Space and Avian Conservation scenarios have the least impacts. The Avian Conservation scenario restricts development within the highest priority habitat (riparian), which results in more native species habitat loss than in the Open Space scenario.

Conclusion, Summary and Recommendations

Summary and Conclusion

Avian diversity in the Truckee Meadows is driven by multiple factors, many of them interacting, to create the urban ecosystem. In the first chapter it became clear that in Reno, and the larger Truckee Meadows, avian diversity is not reduced (in comparison to the larger landscape) like in many larger cities. This pattern appeared to be driven by the Truckee River, despite the presence of urbanization. The conclusion from the first chapter suggested that effective protection of riparian habitat may reduce the effects of urbanization on regional avian diversity. In the second chapter this relationship was explored more, and found that the surrounding land use is likely combining with local vegetation (urban form) to determine the viability of urban habitats for birds. The conclusions from the second chapter suggested that land use planning can play an important role in avian habitat, separate from the vegetation characteristics, highlighting the opportunity for planners to make substantial contributions to urban avian conservation. The third chapter took the relationships established in the first two chapters and developed policies to promote urban avian diversity. These policies were tested in a scenario framework to find that a multi-species open space plan protects a substantial amount of avian habitat, and with little modification could easily account for relationships found in the first two chapters. However, the third chapter also identified the immediate threat the current trend of growth is likely to have on avian habitat in the Truckee Meadows.

It is clear from this research that smaller cities have a different impact on bird diversity than larger cities, and in the case of the Truckee Meadows, may host higher bird diversity than the surrounding landscape. It also appears that these patterns are driven by the types of land uses present around remnant habitat. Landscape features such as the Truckee River are critical for avian diversity, which needs to be considered both in terms of local land use, as well as landscape connectivity. Having major roads, undesignated zoning, or multifamily zoning near riparian habitats can lead to less species using those habitats. A better understanding of why undesignated zoning or multifamily zoning reduces habitat viability will lead to better land use policies, and thus should be a focus for future research. Likewise, not all species distributions were correlated with distance from the Truckee River, so beta and gamma diversity needs to be further studied so land use planning does not compromise larger avian diversity. Roads in general are harmful, but major roads especially (freeways, highways and arterial) have the strongest negative impact on avian diversity. The distinction between road type, road density and distance from road in the first two chapters highlights the need for additional research, as the mechanisms behind those responses are not fully understood. This distinction also highlights the need to look at land use planning variables as discrete variables of important since the distance from a road indicates a different habitat condition than describing the density of roads.

There are clear policy options for protecting avian resources in the Truckee Meadows, and many of those policies already exist within the open space plan. The addition of local empirical research highlights ways in which policies can be adapted to conserve additional avian resources, and comparing policies in a scenario framework demonstrates our ability to find novel conservation opportunities, including increasing riparian vegetation under low growth futures. This research demonstrates the specific ways land use and conservation planners can work together to plan a more coordinated future in the Truckee Meadows.

Urban ecosystems are complex environments (Pickett et al. 1997). The Truckee Meadows offers a unique urban environment with high avian diversity, and with some additional conservation planning, the ability to promote urban avian diversity into the future. Local urban ecological research can help inform land use planning, but needs to be articulated in a way that planners can translate into policies. This research highlights the opportunity for ecologists to use land use planning to describe avian habitat, especially if mechanistic studies can help disentangle the functional differences between land uses. The identification of urban habitat reserves and subsequent protection calls on both ecologists and land use planners to coordinate efforts (Donnelly and Marzluff 2004). Ecologists are better poised to understand the functional differences between urban land uses, while land use planners are better poised to shape those land uses. Future urban ecological research and planning will require substantial coordination, especially as the interrelationships between the heterogeneous habitats present in urban environments are further explored (Pickett et al. 2011).

Recommendations

Future Research

Although McIntyre and Knowles-Yanez (2000) called for a more complete definition of "urban" over 10 years ago, there is still a need for better defining urban patterns and processes that shape urban habitat (Kinzig et al. 2005). The relationship and driving forces among land use, socioeconomics, vegetation and larger landscape features needs to be further described in a flexible way so urban ecological principles can be developed and tested across multiple urban scales and in different urban environments (Cadenasso et al. 2007, Toit and Cilliers 2010). Furthermore, although urban gradient studies have added substantially to our understanding of urban environments (McDonnell and Hahs 2008), not all urban environments have clear gradients of urbanization. Many smaller cities (like Reno and Sparks) have not developed in concentric rings, but grow based on parcel availability and land cost. A more robust method for measuring urban gradients that involves land use variables and vegetation density variables may be more appropriate to measure the transition between urban and rural environments.

Planning Recommendations

The Truckee Meadows has a unique opportunity to enact land use plans that protect the high avian diversity that is found in the cities of Reno and Sparks. Three primary recommendations arise from this research. First, protection and maintenance of the Truckee River riparian corridor is essential, especially in areas with minimal major roads that currently support high avian diversity. Designating open space and parks that connect to these patches, or ensuring that only compatible development is allowed along the Truckee River, will help ensure that surrounding land uses do not reduce the viability of the habitat. Second, connectivity between vacant lots and other remnant rangeland habitat should be maintained, especially in vacant lots that currently host high avian diversity. This can be accomplished through the current open space plan by linking urban habitats via corridors like bike paths or washes, which could help promote native rangeland species. Third, future land use plans should be continually modeled in a scenario framework to identify potential conflicts, or overlaps, between land use plans. The coordination among stakeholders with similar goals, and even more so between stakeholders with disparate goals, is essential for better regional planning. Finally, local scientists need to contribute more to the regional planning efforts. Without local empirical research, key elements of the urban environment may never be recognized. The ecology of cities (Grimm et al. 2000) requires novel thinking about planning and ecology, and will require substantial effort from both land use planning agencies and ecologists to ensure a desirable future. The separation between human and natural environments is blurred in urban ecosystems; however, as this research continues, our understanding of how we as humans fit into the larger landscape will become clearer. Research in urban ecology represents a paradigm shift for ecologists and naturalists, where human-dominated systems are studied in conjunction with natural systems, leading to a more unified view of the landscape.

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