The Role of Urban Forests in Conserving and Restoring Biological Diversity in the Lake Tahoe Basin

Synopsis of Research Results

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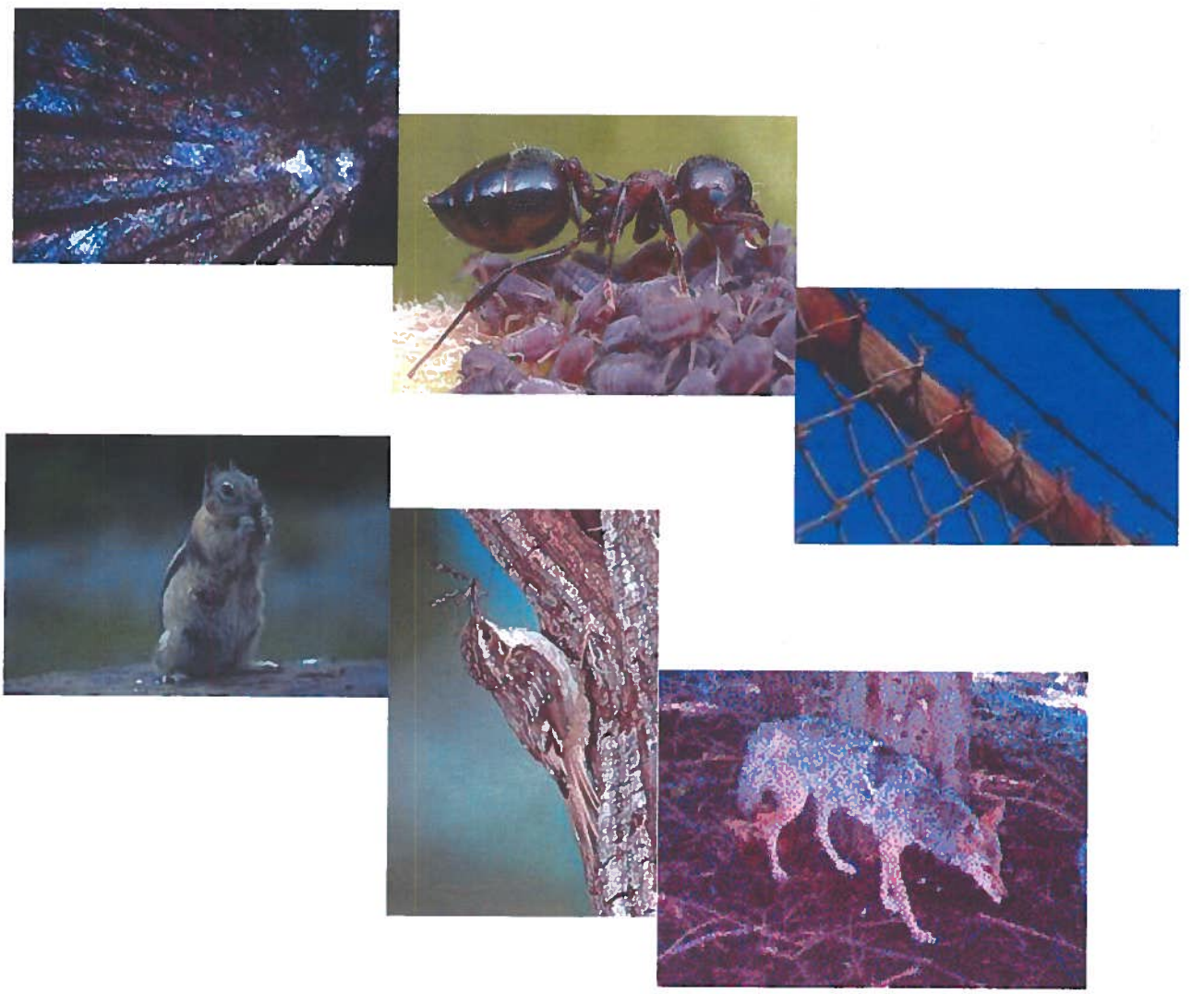

Abstract

This study was conducted to evaluate the contribution of urban forests to supporting biological diversity in the Lake Tahoe basin. A collaboration among scientists from USFS Pacific Southwest Research Station, University of Nevada at Reno, and University of California at Davis, investigated the effects of urbanization and human disturbance on landbirds, small and large mammals, ants, and plants. The results provided insights into the contribution of parcels of undeveloped native forestland to supporting wildlife populations and plant diversity in the basin.

Field data were collected from more than 100 sites distributed throughout the lower montane zone at less than 7000 feet in elevation. Those sites represented a gradient of urban land development from no development within 500 meters of undeveloped forest to nearly 80% developed land surrounding undeveloped forest. Biological conditions and human uses at study sites were characterized. We found that people used undeveloped forest parcels for many activities, but primarily walking in the afternoon and evening, with forested sites in more developed areas generally receiving more use than those in less developed areas. Dogs were detected on over half of the sites, and they were almost three times more likely to be unrestrained in more developed areas (> 40%) compared to less developed areas (<10%). Remnant forests in developed areas retained much of their original vegetation structure and composition, with the important exceptions of reductions in snags, logs, and saplings, and increases in exotic plants. In contrast, the surrounding landscape lost many structural characteristics; however, surprisingly, that one forest characteristic that was not significantly altered in remnant forests or the surrounding landscape was the availability of larger diameter trees.

We found that urban forest parcels supported a wide array of biota, and that the proportion of the landscape maintained in native forest had significant effects on the richness, abundance, and/or productivity of species in many different taxonomic groups. The primary elements of biological diversity that declined with increasing development included bird species richness and evenness, the abundance of numerous ground and shrub nesting birds, the abundance of two specialist chipmunks and the northern flying squirrel, the presence of martens and mustelids, the evenness of abundance across diverse ant species, and the abundance of select specialist ant species. In most cases, declines in biological diversity in (or proximal to) undeveloped parcels were observed when development exceeded 40%, even among many of the individual species and groups of species that benefited from the presence of some development. Although parcels zoned for single-family homes generally retain nearly 50% of their area in permeable surfaces, the vegetative, edaphic, hydrologic character of these remaining areas is often highly altered. Undeveloped forest parcels, therefore, make important contributions to reducing the density of urban land development, thereby maintaining native biological diversity.

The management of urban forest parcels can have considerable effect on their ability to support native biological diversity. Maintaining the original character of parcels can have substantial positive influences on the many species that tend to decline with development. The retention of snags and logs in urban forest parcels, retention of understory vegetation, and control of exotic plants are valuable steps. Balancing these needs with fuel reduction objectives will be challenging. The level of human use often had a negative effect on the richness and abundance of the biota, which appears to be a function of the presence of people and dogs. Measures that might enhance the coexistence of people and biological diversity include creating and directing users to designated trails, and encouraging dog owners to supervise their dogs. Challenges and opportunities exist in balancing objectives of maintaining biological diversity, reducing the threat of fire, and providing a quality living and recreating experience for residents and visitors alike.

Background

A study was initiated in 2002 to evaluate the contribution of urban forests to supporting biological diversity in the Lake Tahoe basin. The study was collaboratively funded by the USFS Lake Tahoe Basin Management Unit, University of Nevada Reno, Tahoe Regional Planning Agency, USFS Sierra Nevada Research Center, Nevada Division of State Lands, and Southern Nevada Public Lands Management Act funds. The study investigated the effects of urbanization and human disturbance on landbirds, small mammals, large mammals, ants, and plants. The study was initiated to develop inferences about the contribution that parcels of native forest (i.e., undeveloped parcels) make to supporting wildlife populations and biological diversity in urbanizing settings.

The science team consisted of Forest Service scientists and University professors and graduate students from the Sierra Nevada Research Center of the Pacific Southwest Research Station, University of Nevada at Reno, and University of California at Davis. The diversity of team members brought a great depth and breadth of expertise to the study, including ecological insights from a long history of working in the Lake Tahoe basin and the Sierra Nevada.

~ Science Team ~

PSW Sierra Nevada Research Center	University of Nevada, Reno	University of California, Davis
Patricia Manley, Ph.D. – Principle investigator	Dennis Murphy, Ph.D. – Principle investigator	Matthew Schlesinger, Ph.D. – Landbirds
Lori Campbell, Ph.D. – Large mammals	Susan Merideth – Small mammals	Kirsten Heckmann – Plant species and communities
Sean Parks – GIS	Monte Sanford – Ants	Marcel Holyoak, Ph.D. – Professor
	Peter Brussard, Ph.D. – Professor	Michael Barbour, Ph.D. – Professor

Introduction and Methods

Multiple state and federal agencies in the Lake Tahoe basin have land acquisition programs that purchase parcels of land, which are sensitive to management or serve important ecological services, such as wetland areas in residential or commercial zones, or flood plain areas in sensitive watersheds. The U.S. Forest Service manages the greatest acreage of urban forests of any agency in the basin, 5200 ha (13,000 ac) of land in 3500 separate parcels, for an average parcel size of 1.5 ha (3.7 ac). In 2002, this study was initiated with the intent of evaluating the contribution of urban forests in supporting biological diversity in the Lake Tahoe basin. The project was funded by the USFS Lake Tahoe Basin Management Unit, USFS Sierra Nevada Research Center, Nevada Division of State Lands, University of Nevada, Reno, and Tahoe Regional Planning Agency. An eight-person science team, which consists of Forest Service scientists, University professors, and graduate students, was assembled to accomplish the task.

This final report summarizes the activities and results of the study. Five taxonomic groups were investigated across a gradient of land development: birds, small mammals, large mammals, ants, and plants. A sampling frame was established based on development within a 300-m radius of a given site. The number of sites sampled for each taxonomic group ranged

from 70 to 130, with approximately 60 sites sampled for all taxa. Sites were located all around Lake Tahoe. The level of development at sample sites ranged from no development within 500 m, to nearly 80% developed within 300 m.

Many sampling methods were employed over the three-year period of data collection (2003-2005). Bird species composition, density, reproductive success, and behavioral patterns of passerines were characterized at a total of 75 sites using three techniques: point counts (75 sites), nest monitoring (97 sites), and behavioral observations (75 sites). Sciurid populations were sampled over a three-year period using Sherman live trap grids (64 traps) at 65 sites, 25 of which were sampled each of three consecutive years. Medium- to large-bodied mammals were surveyed over a two-year period (2003-2004) at a total of 77 sites using track and photographic surveys (four track plate boxes and two cameras), and pellet-group counts (for deer and leporids). Ground-dwelling ants were sampled over a two-year period (2003-2004) at a total of 120 sites using pit-fall trap grids (12 traps). Plant populations were characterized over a two-year period (2003-2004) at 100 sites with a variety of sampling methods, including fixed plots, quadrats, and line intercepts to characterize plant species composition and structure. Human use of the sites was characterized in 2003 and 2004 in terms of types, intensities, and spatial and temporal distribution of anthropogenic disturbance by conducting visual encounter surveys along transects at the same 100 sites sampled for plants. Preliminary results indicate a variety of positive and negative relationships between development and the composition and abundance of plant and animal species.

Results

Human Use

Human use was not closely related to levels of development; human activities measured and number of vehicles documented were only slightly more frequent in more developed areas. Therefore, the effects of human use could be analyzed independently from development. The number of people detected per site ranged from 0 to 11 people per hour, with the exception of one site with over 30 people/hr. Use by people varied depending on the month, time of day, and time of week. Usage peaked in July, followed by August and June. Use was greatest on the weekends, and it was heavier in the afternoon and evening than in the morning. This indicates that summer visitors comprise a large proportion of users of these urban forest parcels, which is perhaps a new perspective on how many visitors spend their time and what aspects of land management in the basin will affect visitor satisfaction. The greater level of use in the latter portion of the day is consistent with the idea that most people go for walks with or without pets toward the end of the day. Dogs were detected on over half of the sample sites. The number of dogs detected per hour per site ranged from 0 to 4.5, with 72% being unrestrained. Dogs were more likely to be restrained in more developed areas.

Human use patterns were positively related to development within 300 m of the site center, and the number of vehicles showed an even stronger positive relationship with 300-m development. So, although use was positively related to development, it was clear that some sites with low development received high use, particularly non-motorized use. Moreover, it appears that some types of impacts associated with dogs (e.g., wildlife harassment and mortality) can be as great or greater in less developed areas because a greater proportion of dogs are unrestrained.

Plants

Native vegetation was not greatly altered in remnant forests that occupy undeveloped near-urban parcels in response to increasing surrounding development. Total species richness increased slightly with development, primarily due to increased numbers of exotic herbaceous plants and native herbs and grasses. Urban development did not appear to negatively affect percent cover of native annual herbs, perennial herbs, and shrubs. In remnant forests, surrounding urban development also had no impact on tree species composition, density, basal area, or the diversity of height classes occupied by vegetation. Decadence features in live trees showed no obvious correlations with development or any other environmental factors; but disease was prevalent, suggesting that many trees are stressed as a result of high densities or drought stress or both. Urban development was strongly associated with the loss of dead wood in the form of snags and logs; snag density, snag volume, and volume of coarse woody debris were all strongly negatively correlated with development, while number of cut stumps was positively correlated.

In the surrounding landscape, forest structure changed far more dramatically in association with increased development. Unlike remnant forests landscape, shrub cover canopy cover, and the density of small and medium diameter trees declined in the surrounding landscape with increasing development. Although the density and condition of snags and logs declined in remnant forests by 50-75%, they declined more drastically in the surrounding landscape (> 80%). These results indicate that remnant forests serve to retain many characteristics, functions, and services in the urbanizing landscape that would otherwise be lost. Retention of snags and logs, and careful monitoring and control of exotic plant species, could enhance the contributions that remnant forests make in urbanizing areas of the Lake Tahoe basin.

Birds

We detected 67 native landbird species, excluding waterbirds and raptors. Species richness ranged from 5 to 28 species and abundance ranged 5.3 to 59.0 individuals per site. We located and monitored nests in these sites, and an additional 22 sites, for a total of 97 sites. A total of 566 nests were discovered and monitored for productivity. Bird species richness declined substantially with increasing development, with the species negatively affected primarily ground-associated or cavity-nesting species. We did not see a strong pattern of association between total bird abundance and development, but abundance was closely associated with landscape vegetation and secondarily associated with human use. Landscape vegetation associations suggest that the amount and type of vegetation retained in the urbanizing landscape affects bird abundance, as well as species richness. Abundance of individual species groups were associated with local vegetation features most relevant to their niche – invertivores responded to canopy cover, ground nesters responded to herb cover, cavity nesters responded to snag densities. Human use was consistently more important in explaining abundance of species groups than percent development. The abundance of some bird species and species groups responded positively to human use (e.g., ground-foraging omnivores), while others responded negatively (e.g., ground nesters).

The GIS-based predictive model for species richness and dominance showed similarly strong associations with development. For species richness and dominance, we observed a

strong influence of both environmental factors and urban development. The final GIS models for cavity-nester and ground-nester richness were more strongly associated with habitat, but showed associations with urban development at larger scales (300-1000 m).

Productivity as a function of nest success was evaluated, with species either neutral or negatively affected by nearby development. Nest success was high for cavity nesters and considerably lower for open nesters, whose success was lower with increased development. Among open nesters, shrub and ground nesters fared worse than tree nesters. Development within close proximity to nests (50 m) had a negative effect on daily survival rate of open-nester and cavity-nester species groups, with open-nesting species that are associated with shrub and ground locations faring worse than those located in the understory. Nest success declined with development for three of the 10 individual bird species examined in detail (Dark-eyed junco, Pygmy nuthatch, and Western wood-pewee), and many other common species simply did not nest in urban forests. Dusky Flycatcher did not nest in areas with > 10% development. Human structures were used for nesting by six species, mostly cavity nesters; the reduced density of snags and small trees in more developed areas may precipitate greater use of buildings and other structures.

Small Mammals

From 2003-2005, over 31,000 trap nights resulted in the capture of 6,400 individuals and 19 species. Total species richness averaged 5.3 species per site (range = 2 to 9), and species richness for squirrels and chipmunks averaged 4 species per site. On average over 95% of individuals captured were squirrels and chipmunks, as opposed to voles, woodrats, or shrews. Long-eared chipmunks were the most evenly distributed across the basin, followed by California ground squirrels, deer mice, and Douglas squirrels. Community composition was significantly influenced by development. Species occurring less frequently with development were shadow chipmunk, deer mouse, long-eared chipmunk, and northern flying squirrel. Species occurring more frequently with development were voles, Douglas squirrel, and yellow pine chipmunk.

We found that development affected small mammal species richness and abundance in a complex manner. The range of species richness values decreased with development: richness values went from a range of 2 to 10 species at lower development to 4 to 7 species at higher development sites. This suggests that sensitive species drop out and species benefiting from development occur more regularly. Furthermore, species richness was positively associated with development within 1 km, but survivorship declined with development at the same scale for most species. This indicates that higher levels of development in the larger landscape may result in species packing in the remaining undeveloped native forests, and that remnant forests with greater surrounding development are likely to become population sinks (the persistence of species at these sites is dependent upon immigration from less developed areas).

Abundance decreased and dominance shifted with the frequency of site use by people more that it responded to development. Yellow pine chipmunk and California ground squirrel were more frequently numerically dominant as development increased, while long-eared chipmunk and shadow chipmunk were less frequently dominant.

Several habitat factors influenced small mammal species richness and abundance. Landscape (habitat) variables that most strongly affected small mammal community measures were cover of bare ground and overall habitat heterogeneity, which both positively affected small mammal species richness and abundance.

The patterns of species richness and relative abundance suggest that remnant forests make an important contribution to sustaining small mammal populations in lower elevation portions of the basin. Reduction in the extent of remnant forests are likely to have negative effects on small mammal populations, particularly more vulnerable species, such as shadow chipmunks and lodgepole chipmunks. As development expands, natural habitat patches decrease in area and survival is expected to decline, likely resulting in a more pronounced change in the richness and abundance of small mammal species.

Large Mammals

Large mammals were sampled at 86 sample sites across the development gradient. Ten carnivores were detected: eight native species, and the domestic dog and cat; in addition, rabbits, hares, and deer were detected. Domestic dogs were the most commonly detected, followed by coyotes, black bears, raccoons, and rabbits and hares. The least commonly detected species were bobcats, weasels, and spotted skunks.

Species richness, ranging from 1 to 6 species, did not differ significantly along the development gradient; however, changes in species composition and the association of both carnivore and herbivore species richness with local forest conditions suggests that undeveloped parcels within developed areas are important to the occurrence of these species. Carnivore species composition differed along the development gradient, with composition at sites at the lower end of the development gradient differed from sites with moderate or high development levels. This indicates that losses occurred at low levels of development (< 30 %), for example, martens and skunks were only documented at sites where development was < 30%. Martens were more frequently detected at the least developed sites (<1 % developed, accounting for 48% of detections), whereas domestic dogs accounted for the majority of detections in areas with higher development.

Species richness and occurrence were influenced by a variety of habitat features. Carnivore richness was most closely associated with microhabitat characteristics, specifically the volume of coarse woody debris, and the density of large and small trees. The best model for marten occurrence was a combined model of human activities and total snag density, and the best model for black bear occurrence was comprised of macrohabitat composition variables, including snags.

Herbivore richness was equivalently related to many environmental variables, although not well predicted overall. Rabbits and hares (leporids) were more strongly associated with local- and landscape-level vegetation than with human activity or development; however, they both were negatively affected by the presence of dogs and vehicles. Both groups were negatively affected by local development and positively associated with development at larger scales, suggesting the importance of remnant native habitats within developed areas.

Development appeared to affect behavior, as reflected in the time of day that individual animals were active. Raccoons are active primarily at night, but appeared to be active more frequently during daylight hours at more developed sites. In contrast, coyotes and bears were detected more frequently during the day at less developed sites. Dogs were generally detected during daylight hours.

The regression models for making landscape predictions were developed for three species that responded to development: martens, black bears, and coyotes. In GIS-based models, coyotes were positively associated with open habitats and development at larger scales, but

negatively associated with local development, suggesting that coyotes benefit from an interspersion of native and urban elements. Marten occurrence was negatively associated with development at multiple spatial scales, but black bear occurrence was most strongly associated with habitat features.

Ants

A total of 32,023 individuals representing 46 species were recorded from the 101 sites sampled. Site species richness ranged from 3 to 20 species, and abundance was a strongly correlated with species richness. Ant abundance was not significantly correlated with percent development at any scale. Conversely, species richness increased in association with development at larger scales, but declined at higher levels of local development, reflecting losses of rare species, which declined with increasing development. Many factors accompany higher levels of development, including ground disturbance and reductions in coarse woody debris (logs), both of which impact ground-associated ant species. Species richness also declined significantly as the total area of compacted surface increased within 30 m. Species richness and abundance declined in proximity to roads and residential developments.

The regression models allowing for landscape predictions were developed for three ant community metrics: ant species richness, log-nester abundance, and thatch-nester abundance. In these GIS-based models, all three groups were driven primarily by habitat features, but features known to be affected by development (e.g., NDVI, canopy cover), so it would be informative to include ants in evaluations of the effects of landscape management scenarios on biological diversity.

Management Applications

Human Use

Given the large number and magnitude of biological responses associated with human use, it seems advisable that human use be monitored as part of routine management activities in undeveloped parcels. Monitoring could include measures of the type and intensity of direct use by people (e.g., walking, jogging, bicycling), and dogs on and off leash. Monitoring ground disturbance caused by human uses is also recommended, given its direct link to uses, and the likelihood that is was responsible for at least some of the relationships observed between human use and biotic measures.

Unleashed dog use appears to have substantial impacts on wildlife. Education can be an effective method to reduce the effects of human use. It would be prudent to identify areas where controlling use (people or dogs) would have the greatest positive effect, such as sites with high biological diversity, unique species, unique habitat conditions, or key locations in the urbanizing landscape.

Plants

Despite increasing extent and intensities of surrounding development, undeveloped forest remnants retained many important characteristic attributes that provide habitat for desired animal species (canopy cover, larger tree density, vegetation height diversity) and that otherwise occur

much less frequently outside the Tahoe basin in developed landscapes. Maintaining undeveloped forest in urbanizing areas contributes ecologically unique and important forest conditions that were shown to support many plant and animal species.

Forest structure is vulnerable to alternation through management and is easily measured. Key measures of forest structure include tree density by size class (i.e., small, medium, and large diameter trees), snag density by diameter and decay class, log density by diameter class and decay class, and vertical layering. Snags and logs are important elements of forest structure that play a vital role in the ecosystem by providing food substrates and habitat, and contributing to nutrient cycling. Current management practices appear to be reducing snag and log densities by 50-75% in more developed areas. Target snag and log densities could be based on a variety of factors, such as vegetation type and special management objectives. Educating and encouraging private land owners to retain more natural forest structure on their properties will also contribute to the maintenance of biological diversity in more developed areas.

Exotic plant species composition and richness are important measures of site conditions, as well as success in minimizing the spread of exotic plants. The control and eradication of exotic species in remnant forests will be important for two reasons: 1) it will reduce the potential spread of exotic plant species into less developed areas; and 2) it will improve the quality of habitat for native plant and animal species within the remnant forest.

Birds

Several species and species groups were strongly associated with development and human activity, and could potentially be used to demonstrate the condition of remnant forests and landscapes. Measures that increased in urban areas included abundance of Brewer's Blackbird, Brown-headed Cowbird, Steller's Jay, and ground-foraging omnivores. Measures that decreased in urban areas, included species richness and the abundance of Dusky Flycatcher, Hermit Thrush, Pileated Woodpecker, Western wood-pewee, ground nesters, and cavity nesters. Surveys that characterize the entire bird community are recommended for assessment purposes, rather than targeted surveys for particular species. Measures of habitat condition most relevant to the bird community include the following: the amount of development (including ground disturbance) within 30 m, snag volume, tree density, shrub and herb cover, and canopy cover (all at the site scale); as well as the amount of conifer vegetation, the amount of aspen and riparian vegetation, and development at the landscape scale ($\geq$ 300 m).

Management at the site scale that is likely to have the greatest positive effect on bird diversity is the retention of snags and logs, and reductions in ground disturbance. Retaining snags, particularly large snags, within Tahoe's urban environments is vital to maintaining populations of many bird species groups. Controlling ground disturbances and improving the retention of understory vegetation (saplings) both are likely to enhance the ability of sites to support ground and shrub cavity nesters there. The retention and restoration of aspen and riparian vegetation in urban forest parcels could also help mitigate the potential impacts of development on ground-nesting and shrub-nesting birds.

Because management scenarios altered both development and NDVI, the scenarios had strong effects on species richness and dominance. Increased intensity of development increased the proportion of the landscape, with low richness and decreased the proportion with moderate and high richness. Maps of model outputs show distinct changes in bird species richness: high-richness areas in the vicinity of South Lake Tahoe, Stateline, Spooner Lake, and Rubicon Bay

reduce in size or disappear completely with increasing development. Reductions in size of high-richness areas are accompanied by increases in size and extent of low-richness areas in most cases. Distinct changes were also observed for species dominance, but not as strongly as species richness. Areas of high dominance expanded with increasing development in South Lake Tahoe, Round Hill/Zephyr Cove, along the east shore from Stateline to Spooner Lake, Incline Village, and the Upper Truckee watershed. Changes in high-dominance areas were accompanied mainly by increases in moderate-dominance areas. The location and extent of urban development will affect bird diversity; models can help inform planning efforts to achieve multiple objectives.

Small Mammals

One of the important landscape features positively related to small mammal species richness and relative abundance was the percent cover of bare ground at a site, most likely because it is limited in occurrence and extent. Dominant vegetation communities influenced both species richness and total relative abundance.

Fuels management activities are the most extensive activities ongoing in native forests in the basin. The removal of some overstory vegetation is likely to benefit many small mammal species, however, wide spacing of overstory trees can impact the ability of arboreal species to move through the forest, potentially increasing their risk of injury and predation. Also, post-harvest treatments, such as chipping and mastication, have the potential to reduce or eliminate herbaceous plant cover and bare ground across large areas of the forest floor, both of which are important contributors to small mammal richness and abundance. Finally, reductions in coarse woody debris (logs) commonly associated with fuel reduction is likely to negatively affect small mammals, more notably in terms of their probability of long-term persistence.

Our results indicate that habitat management can accomplish much to sustain the diversity of small mammals populations. Overall habitat heterogeneity at the site and landscape scales may facilitate the coexistence of a greater number of individuals, as well as individual species. Therefore, managing for a diversity of vegetation types (including aspen, riparian, shrubs, diversity of tree species) at both the local and landscape level would be effective at maintaining small mammal species diversity. Maintaining native forest vegetation within the urban matrix will likely be important for facilitating greater survival rates, and successful small mammal dispersal and movement among forest habitat patches, thus sustaining populations. Maintaining or creating some bare ground in undeveloped forestlands will promote higher species richness without appearing to degrade habitat for any small mammal species. Retaining coarse woody debris will also help retain the diversity and resilience of the small mammal community.

Total species richness and total abundance of small mammals were not strong indicators of land development and human use. The occurrence and abundance of a number of individual species, including long-eared chipmunk, shadow chipmunk, and California ground squirrel, may be good candidate indicator measures. In contrast, species that maybe sensitive to development in one or multiple ways, but may not make good indicators include those that are simply vulnerable to habitat alteration. These species are important to consider as "fine-filter" focal species, including shrews, yellow pine chipmunks, and Douglas squirrels.

Large Mammals

For the carnivore community, the most important habitat characteristics at the site scale included the volume of coarse woody debris, the occurrence of large and small trees, human activity, and development within 50 m. At the landscape scale, the extent of meadow and shrub cover was important. Volume of coarse woody debris, presence of large trees, and proportion of forested area within 300 m were all positively associated with carnivore richness, suggesting the importance of local vegetation characteristics for maintaining carnivores in developing landscapes.

Disturbance from human-related activities, particularly from dogs, had negative effects on some larger mammal species (e.g., rabbits/hares, deer, and black bears). Activity patterns of native carnivores suggested a shift by naturally occurring species to minimize overlap with periods of greatest dog activity (see Fig. 5.6, 5.7). Human activity and the handling of domestic dogs, particularly implementation and enforcement of leash laws, could reduce potential impacts on native species.

Coyotes and raccoons were strongly associated with development, likely benefiting from anthropogenic subsidies. Coyotes and raccoons may reach high densities in urban areas leading to conflict with local residents and the potential for disease transmission to domestic pets and people. Reducing access to pet food, garbage, and other resources (e.g. denning locations) could help reduce densities and the potential for wildlife-human interactions. Coyote populations may warrant monitoring, given that increased abundance of this species could precipitate substantial ecological consequences and elevated conflicts with humans.

Black bear populations are changing in response to changes in human population densities and behaviors. Bears are an important component of the ecological and social systems in the basin. The response of bear to development was not strong; however, it is likely that development and human use is affecting bear populations, but that the probability of occupancy is an insensitive measure of these changes. A bear management plan for the basin, employing monitoring that uses appropriate population parameters, would be a prudent investment to ensure the health and safety of both bear and human populations.

We applied two of the predictive models to the landscape to determine the potential effects of the management scenarios we created. The results of landscape modeling for marten did not indicate significant change in the probability of marten occurrence under any management scenario. This reflects the fact that most undeveloped parcels exist in areas with moderate to high development, which means they have a low probability of occupancy even in an undeveloped state. Thus, the marten is an example of expected responses of species with a low tolerance for development at any scale. The probability of coyote occurrence generally increased with increasing development, although changes were slight, thus modeling indicates the potential for increased conflicts between humans and coyotes with increased development.

Several species and species groups were strongly associated with development and human activity could potentially be used to reflect the condition and contribution of native forests in developing areas. A potential indicator of more developed areas would be the raccoon and coyote. Potential indicators of undeveloped conditions include the occurrence of marten, spotted skunk, and bobcat, and their daily activity patterns (both ready obtained with cameras). Community level surveys are recommended rather than individual species surveys. Survey duration may need to be extended in developed areas to achieve the same survey-level probability of detection as in less developed areas.

Ants

Minimizing the number and extent of areas where development exceeds 30% would greatly help retain native ant populations and communities. Ant species richness was highest in forests of moderate levels of urban development and low development sites contained many unique species. This indicates that rare species are the first to be lost with progressive development. The retention of undeveloped parcels and intact forest structure and composition within them, as well as the retention of native vegetation and coarse woody debris to the extent possible in developed parcels will contribute significantly to retaining native ant biodiversity.

A few strong candidate indicators of site conditions were identified in the course of this study. Community dominance is a good measure of development at the neighborhood scale (within 300 m). Ant species richness appears to be a good indicator of site conditions, declining as sites have increased areas of compacted surface. *Formica cf. sibylla* abundance is likely to be a good indicator of development and associated disturbance, given its consistent negative relationship with development. *Formica ravida* abundance is likely to be a good indicator of development and associated disturbance, given its consistent positive relationship with development. Total abundance and log-nester abundance both decreased in relation to development.

Ant species of concern were identified that are strong candidates for monitoring as "fine filter" elements of native forest ecosystems. Rare species are at risk from development, and monitoring of appropriate ant community metrics could provide reasonable estimates of the fate of rare species as a group. Exotic species, like rare species, would be essential monitoring targets in the course of assessing conditions in urbanizing areas. Species-specific sampling methods for exotic and rare species could be developed to more gauge directly distribution and abundance patterns for future monitoring programs.

Future Directions for Research

Our results have highlighted additional research that would be beneficial in expanding our knowledge of biodiversity in the face of urbanization in the basin. Here is a brief overview of the information needs that have been identified in this study:

Plants

Link between ecosystem services and forest structure and composition – It would be informative to understand the link between the changes in forest structure and composition that typically occur as a result of urban land development and the effect on ecosystem functions and services, such as water retention, sedimentation, nutrient retention, carbon sequestration, and insect and disease control. Additional information on changes in plant species composition in the overall landscape relative to development would provide additional insights into triggers for exotic plant species establishment and cover, as well as the availability of food plants for wildlife.

Old growth forest characteristics – There remain many questions about the target site-scale conditions associated with undisturbed old growth forests. In the pursuit of restoration of old forest conditions in the basin, additional understanding as to the unique characteristics

missing in older forests that have been altered by human activity, including sites in proximity to various levels of development, would provide helpful guidance to management.

Interaction effects of development, human use, and fuels management - Many of the sites we sampled had been managed at some point in the past, as evidenced by the presence of stumps, and many received fuel treatments soon after we sampled them. The effects of forest management are of great interest to land stewards attempting to meet multiple objectives on public parcels. We were able to identify elements of forest structure and composition that were important determinants of various biodiversity metrics; however we did not directly investigate the question of forest management effects that have the potential to functionally extend the detrimental effects of urbanization into less developed areas.

Birds

Landscape configurations most beneficial to supporting bird biodiversity – This project could not evaluate the tradeoffs associated with different landscape planning scenarios in maintaining diversity of birds. This project has generated data that could be readily used to evaluate planning and management tradeoffs throughout the lower montane zone.

Controlling for the effects of human disturbance - The importance of human disturbance in structuring the landbird community indicates a need for a deeper understanding of the mechanisms underlying its effects, particularly on species with characteristics that make them most vulnerable, such as understory specialists. Research into the behavioral responses to different types of activities, their duration, and their timing, would greatly benefit managers looking to control effects of human disturbance on birds.

Conservation of species vulnerable to urbanization – Several species have very low tolerance to urban development and/or human use, such as the Dusky Flycatcher. A more specific understands of factors limiting these populations will help inform effective management to conserve these species.

Degree of impact of nest parasitism - Brown-headed Cowbirds are prevalent in the basin. Whether urbanization facilitates nest parasitism by Brown-headed Cowbirds is an important management question best addressed by nest monitoring of cowbird-sensitive species like vireos and warblers along the urban gradient, which were not target species in this study.

Minimizing the potential for property damage by birds - Use of human structures for nesting by birds in urban areas is an interesting ecological phenomenon and management concern -- under what conditions will birds nest in human structures? Does their willingness to nest in human structures affect their ability to survive in urban areas? How do nesting ecology and reproductive success differ in natural versus artificial nest substrates? Can artificial nest structures be used to effectively enhance habitat conditions for birds in more urbanized environments, and thereby reduce damage to human structures?

Small Mammals

Landscape configurations to enhance small mammal biodiversity - At the landscape scale habitat connectivity affects the ability of a species to respond to environmental change. That connectivity is reduced by urbanization, but the degree to which it is altered can be minimized by controlling the placement and character of urban development. While most forest-associated species in the Lake Tahoe basin do not appear to have reached distribution thresholds with

respect to urban development, maintaining landscape linkages may be crucial for preventing the loss of species. The predictive models developed in this study could be applied to evaluate the potential impacts of various management and development scenarios.

Status and thresholds for vulnerable species - We found compelling evidence that key population processes of survival and emigration of some species are being negatively affected. It is necessary to monitor theses populations over a longer period of time to assess implications for population persistence and how site management can enhance conditions for vulnerable species.

Improved understanding of urbanization effects on specialized species - There were many small mammal species and species groups that we did not capture or sample that are likely to be responding to development and disturbance, and which play important roles in forest ecosystems. Bats are an ecologically important taxonomic group that we did not sample. Small-bodied weasels and flying squirrels were not well sampled by our trapping scheme because of their specialization, yet they play important roles in forest ecosystems as carnivores and fungi specialists, respectively.

Genetic diversity of small mammal populations - Genetic techniques could be used to determine connectivity and genetic distinctiveness among sites around the basin. Combining demographic information from mark-recapture data with genetic survey data would allow inferences about the impact of human development on connectivity of Tahoe basin species at multiple spatial and temporal scales. Furthermore, additional knowledge about habitat connectivity can also influence management strategies, because populations that are sufficiently differentiated may be managed as distinct units in order to sustain populations.

Large Mammals

Landscape configurations most beneficial to supporting large mammals – This project was not able to fully evaluate the tradeoffs associated with different landscape planning scenarios and maintaining the biological diversity of various taxa, including large mammals. This project has generated data that could be readily used to evaluate planning and management tradeoffs throughout the lower montane zone. Additional analyses of these data that would be useful for understand the relationship of carnivores to native forest with an urban environment would be a spatial evaluation of the importance of area and configuration to carnivore occurrence.

Demographic and behavioral research on key species - Further analysis of carnivore activity patterns relative to habitat, development, human activity, and the occurrence of other species (e.g., domestic dogs) would reveal aspects of carnivore behavior that will inform how management can achieve multiple objectives (e.g., forest resources, recreation, wildlife). Further research into bear population demography and behavior in both wildland and urban environments will be needed to inform a bear management plan. Coyote responses to increasing urbanization and human use is also a concern, thus coyote should be considered a key species.

Recreational development effects on key species - Future studies need to address the impacts of other types of development (e.g., recreational development) on wildlife and wildlife habitat. Recreational development may be of a lower intensity but can impact as large or larger areas than residential development and occurs both at lake level (e.g., golf courses) and at higher elevations (e.g., ski areas) in the basin.

Ants

Landscape configurations most beneficial to supporting ant biodiversity – This project was not able to evaluate the tradeoffs associated with different landscape planning scenarios and maintaining the biological diversity of various ant taxa. This project has generated data that could be readily used to evaluate planning and management tradeoffs throughout the lower montane zone.

Habitat restoration effectiveness – Many of the site-scale restoration measures suggested by our research results are expected to directly benefit ants, such as increasing dead wood availability and reducing ground disturbances, particularly those associated with high soil compaction. Ant responses to these restoration efforts could inform their potential to contribute to enhancing ecosystem function in remnant forests.

Interaction effects of development, human use, and fuels management - The effects of forest management and urbanization are intricately linked for ants, which responded primarily at the site scale. There are potentially interactive effects between urbanization and forest management (particularly related to fuels management) that will substantially affect ants and the ecosystem services they perform. Research is still needed to determine how ant diversity is being affected by specific land management practices.