THESIS

SOCIAL AND ECOLOGICAL ASPECTS OF CONSERVATION DEVELOPMENT AS A STRATEGY FOR BIODIVERSITY CONSERVATION ON PRIVATE LANDS

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ABSTRACT

SOCIAL AND ECOLOGICAL ASPECTS OF CONSERVATION DEVELOPMENT AS A STRATEGY FOR BIODIVERSITY CONSERVATION ON PRIVATE LANDS

Private lands harbor a large proportion of the world's biodiversity, and they are also facing widespread threats from extractive land uses, anthropogenic disturbances, and land conversion for residential and commercial development. With decreased funding and support for public land acquisition and management, developing effective and economically viable tools for conservation on private lands is increasingly important. One method is conservation development (CD), an alternative to residential sprawl designed to decrease negative environmental impacts by clustering houses in a small portion of a property while preserving the remaining land as protected open space. Although CD makes up approximately one-fourth of all of the private lands conserved in the U.S., little research has assessed where and why this tool is implemented, long-term management of CD open space, or specific positive or negative effects on wildlife communities.

I conducted a thorough investigation of CD as a private land conservation strategy using a variety of methods. In chapter one, I investigated CD's ability to successfully protect animal populations by examining bird and mammal occurrence in 14 CD subdivisions (range: 14-432 ha) in Northern Colorado, USA. Using point count and camera trap data in an occupancy modeling framework, I evaluated the relative importance of 9 subdivision design factors (e.g. housing density, proportion of CD preserved, total area of the protected space) and 14 stewardship factors (e.g. mowing, livestock, native vegetation cover) in influencing the richness

of human-sensitive and human-adapted species and probability of use by 16 birds and 6 mammals. I found that bird and mammal species richness and habitat use were associated predominantly with design characteristics that maximize the natural or undisturbed land area both within and surrounding the development (e.g., proportion of CD preserved, total area of the protected space, proportion of natural land cover types at large scales). Habitat use by birds was frequently influenced by local habitat composition and quality, and several bird and mammal species had decreased habitat use in areas with increased localized disturbances such as the presence of humans and mowing in the open space.

In chapter two, I used Social Network Analysis (SNA) to examine participation of individuals and companies (actors) in CD implementation. Using data gathered from public county records, I quantified actor participation in CD subdivisions in six counties in Colorado, USA. I examined and compared the patterns of actor participation in CDs among counties and identified the individuals and organizations that were most consistently associated with the implementation of CDs within each county. I found that social networks of actor participation in CD differed among counties, and network characteristics varied depending on the population of the county, the total number of CDs in the county, and the total number of actors in the network. My results also showed that the most highly connected actors that were consistently involved in the implementation of many CDs were biological and geological consultants, surveyors, engineers, and planners.

In chapter three, I formally assessed the content of management plans and conservation easements for existing CD subdivisions in six Colorado counties. I quantified the proportion of CDs with management documents. I also examined the land uses and stewardship activities that were prohibited, permitted, encouraged or required in the protected open space of existing CDs. I determined which activities and practices were most and least frequently addressed in these documents in order to prioritize strategies to improve CD as an effective private land conservation tool. More than two-thirds (69%) of 302 CDs had documents on file that included guidelines and regulations for the long-term stewardship of the protected land. However, CD management documents rarely mentioned issues relating to wildlife habitat improvement, species-specific monitoring and management, homeowner education, and access to the open space by domestic pets.

This research identifies several key design and stewardship factors that influence the conservation value of CD open space for birds and mammals, and the key actors and actor types in CD implementation. These findings can inform the strategies used to communicate recommendations to improve CD effectiveness at achieving conservation objectives. This research also examines the current strengths and weaknesses in the documents that guide stewardship of CD subdivisions. Using these findings, I made recommendations for critical guidelines and regulation that should be included in management documents to attain conservation benefits. By incorporating characteristics that promote the persistence of sensitive animal species on private lands, CDs have strong potential to balance the housing needs of growing human populations with the preservation of diverse and abundant animal communities. With direct application to improving the way that CDs are designed, developed and managed, my findings could enhance the potential of CD to sustain native biodiversity on private lands.

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CHAPTER ONE

EFFECTS OF CONSERVATION DEVELOPMENT DESIGN AND STEWARDSHIP ON BIRDS AND MAMMALS IN NORTHERN COLORADO

INTRODUCTION

Private lands offer substantial but historically overlooked potential for the conservation of biological diversity around the globe. Most of the world's land area is privately owned, including 60% of the U.S. (National Wilderness Institute & U.S. Bureau of the Census 1995). Private lands are also located non-randomly on the landscape. They tend to occur at lower elevations and in more productive areas, places that are often more ecologically diverse than public lands (Joppa & Pfaff 2009, Scott et al. 2001). As a result, private lands harbor a large proportion of the world's biodiversity and are also much more likely to be threatened by extractive land uses, anthropogenic disturbances, and land conversion for human development (Knight 1999; Miller & Hobbs 2002). With a rapidly expanding human population and decreased funding for public land acquisition and preservation (Cohen 2003; McCarthy et al. 2012), new conservation strategies that target areas undergoing urbanization are becoming more essential to combat global biodiversity loss.

Residential and commercial development on private lands is estimated to be responsible for the decline of 35% of the nation's 1,880 imperiled plant and animal species (Wilcove et al. 1998). Residential sprawl, or exurban development, is expanding rapidly throughout the United States, and currently makes up five times more land area than all of urban and suburban development combined (Theobald 2004). One strategy used to preserve private lands is conservation development (CD), which seeks to minimize the impacts of residential and commercial development on natural resources (Pejchar et al. 2007). While CD can refer to development projects with a variety of project goals, actors, and land use patterns (Milder & Clark 2011), here I use the term to refer to conservation development subdivisions, an alternative to residential sprawl designed to decrease negative environmental impacts by clustering houses in a small portion of a property while preserving the remaining land as protected open space (Figure 1) (Pejchar et al. 2007; Milder 2007). In theory, CD offers a "win-win" solution in which the preservation of biodiversity and the housing needs of a growing human population can be balanced. However, little is known about how CDs function to preserve wildlife habitat, and how they can be modified or improved to support species that may not persist in traditional exurban areas.

CD has been in use for over four decades and represents approximately one fourth of private lands conserved in the United States (Milder & Clark 2011). Although CD occupies four million hectares of land (Milder & Clark 2011), it contributes a relatively small proportion of the total residential housing in the U.S. For example, in Colorado, CDs comprise approximately 4% of the residential housing in unincorporated areas of select counties (Mockrin et al. In Review). In the western U.S., CD implementation is often regulated and encouraged via ordinances adopted by county planning agencies (Reed et al. 2014). County agencies may employ land-use regulations such as development codes, zoning ordinances, or subdivision regulation (Jurgensmeyer & Roberts 1998; Ellickson & Been 2000; Pejchar et al. 2007). Counties may also provide incentives, such as density bonuses or an expedited review of development proposals, to encourage participation in voluntary CD regulations (Pejchar et al. 2007; Reed et al. 2014).

Currently, over 30% of counties in the western United States have ordinances regulating CD (Reed et al. 2014).

A few authors have drafted guidelines for the design and stewardship of CDs, including the book by Randall Arendt, "*Conservation Design for Subdivisions,*" which popularized the practice after it was published in 1996 (Whyte 1964; Arendt 1996; Hostetler & Drake 2009; Hostetler 2012; Hostetler & Reed 2014). However, these guidelines rarely make their way into regulation, and several authors have pointed out inconsistencies or potential problems with the way that CD is currently implemented. In some counties, existing permitting processes and zoning ordinances may act as significant barriers to CD implementation (Allen et al. 2013), and ordinances that lack rigorous guidelines for natural resource protection may result in compromised environmental goals (Gocmen 2013). Many papers have emphasized the importance of assessing the property prior to the design phase in order to identify and preserve ecologically valuable attributes (Pejchar et al. 2007; Carter 2009; Hostetler & Drake 2009). However, only 5% of CD ordinances in the western U.S. require that developers perform an ecological site analysis prior to designing the subdivision (Reed et al. 2014). In some cases, houses may be intentionally located near environmentally sensitive areas, such as lakeshores (Gonzalez-Abraham et al. 2007). Design characteristics such as the size and configuration of the protected area also vary significantly between CDs. Few ordinances specify a minimum size of the protected open space, and only 27% stipulate that the open space be contiguous within the CD parcel (Reed et al. 2014). Finally, ongoing stewardship of CD protected space may be insufficient (Wald & Hostetler 2010; Hostetler 2012). Only 28% of CD regulations in the west encourage land management after a subdivision has been constructed (Reed et al. 2014), and developers and homeowners often lack the funding, interest, or expertise to support long-term stewardship of the open space (Lenth et al. 2006; Feinberg et al. 2015).

Because there is limited regulatory oversight guiding effective design and management strategies, the practice of CD can vary widely. In some cases, CDs may have similar effects on bird and mammal communities as traditional residential development. A previous study in northern Colorado by Lenth et al. (2006) found that human-sensitive mammal detections, bird densities, and nest survival did not differ between traditional and clustered subdivisions, and they were significantly lower when compared to undeveloped protected areas. The authors were surprised by this result, and they suggested several possible explanations for the comparatively low conservation value of clustered subdivisions. First, they noted that the clustered subdivisions they sampled were substantially smaller in size than the undeveloped areas (the undeveloped areas were on average 400 ha larger than the clustered sites), which may render a majority of the land exposed to "edge effects" from housing development despite the clustered configuration (Odell & Knight 2001). Second, they observed that the plant communities were dominated by non-native species in both the clustered and traditional subdivisions, while the undeveloped areas were dominated by native species. Native vegetation cover is more likely to attract and support native wildlife communities (Winter & Faaborg 1999), whereas non-native vegetation may attract generalist or human-tolerant species to housing developments (Hansen et al. 2005). Third, the authors hypothesized that certain wildlife species may have been negatively impacted by disturbances that occurred in the clustered subdivisions, such as humans and their pets frequenting the protected open space (Hansen et al. 2005).

In this study, I used the findings of Lenth et al. (2006) as a starting point to identify and investigate a suite of design and stewardship factors that influence how birds and mammals use

CD open space. To examine how CD characteristics affect community composition and habitat use by birds and mammals, I selected 9 design factors and 14 stewardship factors that I predicted would influence how different species use CD protected open space. I hypothesized that native and human-sensitive species would be more likely to use large, contiguous open space exposed to minimal negative impacts by housing development. These site characteristics could be facilitated by preserving a larger area and proportion of the development as open space, and clustering the houses at high densities in a small portion of the development. At a broader scale, I predicted that human-sensitive species would be more likely to persist in CDs that are adjacent to other natural or preserved land, and that are located in a less developed landscape matrix. I also predicted that human-sensitive species would be more likely to use open space with more native plant cover. Finally, I predicted that local anthropogenic disturbances, such as the presence of humans, pets, or livestock in the open space would decrease habitat use by human-sensitive species, and that resource subsidies such as non-natural water sources, trashcans, and birdfeeders, would increase use by human-adapted species.

I collected detection/nondetection data on birds and mammals from noninvasive sampling, and I used species richness and occupancy modeling approaches to evaluate how design and stewardship factors influenced the probability that human-sensitive and human-adapted bird and mammal species would use the open space of 14 CDs and 4 undeveloped areas in Boulder and Larimer counties, Colorado (U.S.A.). Specifically, my study questions were: 1) Which design and stewardship characteristics are most important for influencing bird and mammal richness and use of CD open space?; and 2) How do these factors affect species occurrence and use of these areas by different groups of species (e.g., human-sensitive, human-adapted)? Understanding how CD design and stewardship influences wildlife communities will help generate strategies to improve the way that CD is currently implemented, maximizing its potential as a private lands conservation strategy.

METHODS

Study Area

This study took place in eastern Boulder and Larimer counties, in northern Colorado, U.S.A. (Figure 2). Situated at the junction where the Great Plains meet the Rocky Mountains, this area encompasses a wide range of elevation and habitat types. The two major ecoregions are the Southern Rocky Mountains and the Central Short Grass Prairie (Doye et al. 2004; Neid et al. 2009). This area is experiencing steady human population growth and residential development, and the population is expected to increase by almost 25% in the next 15 years (Colorado Department of Local Affairs 2013). Half of the land in Boulder and Larimer counties is privately owned, with most of this private land located at lower elevations in the eastern portion of the county, or near major towns in the western region (Neid et al. 2009). A series of cities run along the eastern section of Boulder and Larimer counties, including Fort Collins, Loveland, Longmont, and Boulder. This urban corridor contains productive soil and critical wildlife habitat (Wallace 2008), but it is disproportionately affected by habitat loss and fragmentation from residential development.

As of 2010, Colorado had a total of 352 CD subdivisions (Hannum et al. 2012). Boulder County and Larimer County have the largest numbers of CDs in the state, with 143 and 89 respectively (Mockrin et al. In Review). The majority (97%) of CDs in Boulder County were built in the 1980's and early 1990's, and the mean approval date for all CD projects in this county was 1986. In Larimer County, the majority (99%) of CDs were built during the 1990's and 2000's, and the mean approval date for all CD projects in this county was 2002.

Site Selection and Study Design

My study sites were located in 14 CD subdivisions and 4 undeveloped areas within Boulder and Larimer counties (Figure 2). I selected CDs using data collected by the Global Challenges Research Team on Conservation Development, a working group in the School of Global Environmental Sustainability at Colorado State University. I also used information from the Colorado Ownership, Management, and Protection (COMaP) data set (Lavender 2011) to select CDs depending on their size and spatial characteristics. Potential study areas were limited to an elevation range of 1500m-1900m in order to minimize ecological variation among sites. Because I hypothesized that total size of the open space would be an important factor influencing wildlife occupancy in these developments, I created an even distribution of study areas of differing sizes. To do this, I stratified subdivisions into four size classes (<30 ha, 30-70 ha, 70-200 ha, >200 ha) and selected up to four CD subdivisions in each category. I also restricted potential study areas to subdivisions with open space that consisted of no more than 50% intensive agriculture. This ensured sufficient area for data collection in natural or semi-natural plant communities, and limited the influence of agricultural activities on my bird and mammal observations.

After identifying potential study areas that met these criteria, I sent letters to landowners in 20 CDs to request permission to access the open space in their subdivision. Landowners responded by phone or email to grant or deny permission. Some subdivisions had conservation easements held by land trusts, the county, or the city. If landowners from these developments granted permission, I also requested and obtained permits from easement holders associated with the open space in these subdivisions.

Four undeveloped protected areas were selected to provide a range of undeveloped comparison sites for the CDs. While the main focus of the study was to explore bird and mammal occurrence within CDs, I chose to sample a small number of undeveloped areas in order to provide reference points for species occurrence in similar private protected land without housing. I selected undeveloped areas within the same elevation gradient and geographic distribution as the CDs, and I restricted potential study areas to those that were closed to public access and were not bisected by roads or trails. I selected one area from each of the size classes used to select the CDs and sought permission to access the area. The final group of study areas included eight CDs and three undeveloped areas in Boulder County, and six CDs and one undeveloped area in Larimer County. The CDs ranged in size from 14 ha to 432 ha (mean 119.13; SE 32.32), and the undeveloped areas ranged in size from 28 ha to 264 ha (mean 106.63; SE 53.53).

I selected a maximum of eight sampling points in each study area using stratified random sampling in ArcGIS (ESRI 2013), and I ensured that the points were at least 200m from other sampling points. Because I was interested in measuring species habitat use of the protected open space, points were located at least 50m from a private lot or the edge of the development. Five of the 14 CD subdivisions and one of the undeveloped areas were too small to accommodate eight sampling points; these sites were assigned between three to seven sampling points. In total, 97 sampling points were established within CD subdivisions, and 27 sampling points were located in undeveloped areas (Figure 2).

Bird Surveys

I conducted unlimited-radius, five-minute bird point count surveys at each sampling point where I identified all passerine and near-passerine species present during the sampling period by sight and sound. All point counts were conducted by a single trained observer (CMF). I also recorded each bird's behavior, substrate where it occurred, and distance from the observer. Afterwards, I truncated species detections at 100m from the sampling point to ensure independence between sampling sites. Point counts were conducted during two breeding seasons, May-June 2013 and 2014, and sampling took place during periods of maximum activity, from five minutes after dawn until 10:00am. I visited each sampling point on a total of three separate occasions throughout the sampling period, or approximately every two weeks during each breeding season.

Mammal Surveys

I placed remotely-triggered cameras ("camera traps") at up to four of the sampling points within each study area, for a total of 55 camera sampling sites in the CDs and 16 camera sampling sites in the undeveloped areas. Camera trap sampling points were dispersed throughout the open space portion of the subdivision to capture potential variability in mammal occupancy within the area. Cameras were not baited in order to avoid potential behavioral modification and biases that occur when using scent lures (Kays & Slauson 2008). Each camera trap was placed within 100m of the sampling point and located strategically along a potential animal movement route (e.g. wildlife trail, fence line, culvert, drainage) in order to maximize the probability of detection (Rowcliffe et al. 2008). Cameras were deployed for four weeks (28 trap-days) per season during two summer sampling seasons (June-August 2013 and 2014), and one winter sampling season (December 2013- January 2014) for a total of 84 trap days per sampling site.

Design, Stewardship, and Habitat Variables

I identified nine design factors, 14 stewardship factors, and four other site variables that I hypothesized would influence the probability that birds or mammals would use CD open space (Table 1). I used a combination of field measurements, aerial imagery, and geospatial software to quantify each variable.

I measured the spatial characteristics of each site using the COMaP dataset and ArcGIS 10.2 (Lavender 2011; ESRI 2013). I used the aerial World Imagery Basemap (ESRI 2014) as a reference and manually digitized houses in ArcGIS to calculate housing densities at multiple spatial scales surrounding the sampling points. Using information from the Southwestern Regional GAP Analysis database (USGS National Gap Analysis Program 2011), I measured the composition of the landscape matrix at several spatial scales by measuring the proportional land cover of forest, shrubland, grassland, and agriculture at multiple buffer distances around the sampling point. I also measured the proportion of natural land cover, which included all vegetated land cover types, but excluded agriculture, recently disturbed or modified land and land that is developed or in other human uses (USGS National Gap Analysis Program 2011). Housing density and all land cover types were measured at local scales (within 200m and 500m of each sampling point), at broad scales (within 1km, 2km, and 3km of each sampling point), and at a buffer distance scaled to the average home range size for each mammal detected in the study (Irvin et al. 2013).

I used both visual observations and camera trap data to measure stewardship variables that I hypothesized would influence wildlife habitat use at each site, including non-natural structures, human and domestic animal disturbances, and land management activities. I recorded the distance to and number of resource subsidies (e.g., bird feeders, trashcans, non-natural water sources) and light sources (e.g., porch lights, street lights) that were present within 200m of the sampling point. I used visual observations as well as camera trap photographs to determine the presence and relative activity of livestock, humans, and domestic animals. I also recorded traffic volume (vehicles/minute) on roads within 200m of the sampling point.

I collected data on vegetation structure and composition within nine $1m^2$ plots at each sampling point (Bonham 1989). At six of these nine plots, located randomly within 100m of the sampling site, I recorded the percent cover and height classes of shrub, tree, forb, grass, woody debris, bare ground, rock, litter, cactus, manicured lawn or crop. In an additional three locations, all within 10m of the sampling point, I identified all tree, shrub, forb, and grass species within the plot, and recorded their percent cover and origin (i.e., native, exotic). I indicated whether any plants were classified as noxious weeds in the Boulder County Noxious Weed Management Plan or the Larimer County Noxious Weed Act. I also noted whether the area was grazed or mowed, and the most recent mowing date, if known. Finally, I estimated canopy cover at each sampling point using a densiometer.

Observed Species Richness

To investigate the effects of CD design and stewardship on community composition of birds and mammals, I used linear regression to relate the observed species richness for different groups of species to each design and stewardship factor. I tested whether species' responses to CD design and stewardship differed as a function of their sensitivity to human disturbances by classifying each bird and mammal into two separate groups: human-sensitive and human-adapted (Appendix 1, Appendix 2) (Martensen et al. 2012). I used the scientific literature to classify species into the two groups using the following criteria: if the species maintained or increased in abundance, occupancy, or habitat use in response to increased housing density, it was classified as human-adapted (Odell & Knight 2001; Lenth et al. 2006; Goad et al. 2014). If the species decreased in abundance, occupancy, or habitat use due to increased housing, it was classified as human-sensitive (Odell & Knight 2001; Lenth et al. 2006; Goad et al. 2014). If possible, I consulted references that investigated the species in Boulder or Larimer County, or in the state of Colorado. If species responses to housing density differed between references, I classified the species according to the reference that was geographically closer to the study area. The number of species within each group observed across all sampling occasions at each site was used as the measure of human-sensitive species richness and human-adapted species richness.

I built multiple linear regression models with Poisson error structures using human-sensitive species richness and human-adapted species richness as the response variable for both birds and mammals (Crawly 1993). I tested for collinearity among predictor variables using Spearman's correlation coefficient (Whittington et al. 2005), and I did not include any variables with a correlation greater than 0.7 in the same model set. I first built models to test for the best supported scale for the landscape and housing density covariates. I then built a final model set that included single factor linear relationships of each design and stewardship factors (Table 1), models that exhibited a quadratic relationship for each factor, and a model that indicated constant species richness across sites. I calculated Akaike's information criterion adjusted for small sample size (AICc) to rank and compare models (Burnham & Anderson 2002), and examined the regression coefficients to determine the direction and strength of each design and stewardship factor.

Species Occupancy

I used a multiple-season occupancy modeling framework to determine how design and stewardship factors influence bird and mammal occurrence within CDs. Many sampling methodologies, and especially non-invasive wildlife surveys, result in imperfect detection of a target species. Occupancy modeling can correct for the biases that occur when species go undetected despite being present (MacKenzie et al. 2006). Repeated detection and non-detection surveys collected during each sampling season are used to estimate the probability of occurrence (ψ) and the probability that a species is detected given that it occurs in an area (p) (MacKenzie et al. 2006). Colonization and extinction rates (γ and ε) are also estimated by using a "robust design" in which winter or summer seasons are delineated as the primary sampling period, and each independent point count or week-long camera deployment is a secondary sampling occasion within the season (Pollock 1982, MacKenzie et al. 2003, 2006).

Bird detections were recorded within 100m of the sampling point, and mammals were detected if they passed through the camera trap's range of detection (within approximately 15m). Therefore, sampling sites were often smaller than an average individual's home range, and the occupancy modeling assumption that each sampling unit was closed to local extinction and colonization during a sampling season was not necessarily met for all sampling sites. It is reasonable to assume, however, that individuals moved in and out of the sampling sites randomly during the sampling season. In this case, the results are not biased, and the random inter-seasonal movement is incorporated into the probability of detection (Tyre et al. 2003; MacKenzie et al. 2006). Occupancy estimates should therefore be consider as the species' probability of "use" during a season rather than true occupancy of the site (MacKenzie et al. 2006).

I used a set of criteria based on detection data to select species for occupancy modeling. Species with under approximately 20 detections had convergence issues and were eliminated. Because I was interested in examining how species varied between sites based on CD characteristics, I also eliminated species that I detected at over 90% of the study sites. To avoid overfitting the occupancy models, I eliminated one of each set of covariates that had a correlation greater than 0.7 (Burnham & Anderson 2002; Alin 2010).

Using package RMark (Laake & Rexstad 2008) in R (RDevelopmentCore Team 2014), I built and tested competing models relating predictor variables to the probability of site occupancy for each species. I used an ad-hoc hierarchical model building procedure (Doherty et al. 2012), in which I first ran models to determine whether detection probability (p) was constant, varied by season, or varied by a series of detection covariates (Table 2) while occupancy (ψ) was held at the global structure. I then used the set of all supported structures for detection probability (≤ 2 ΔAIC) to assess whether colonization (γ) or extinction (ε) rates were constant, fixed to 0, or varied by the design and stewardship factors (Table 1). Next, I evaluated models to determine the best-supported scale for each of my land-cover and housing density covariates: 200m, 500m, 1km, 3km, 5km, or scaled to the species' average home range size ("HR"). Finally, I used the resulting best structures to build single-effect, additive, and interaction models with a maximum of two covariates to examine whether species occupancy (ψ) was constant or varied with the site-specific design and stewardship factors of interest (Table 1). I conducted a separate analysis to determine whether habitat use differed between the CD subdivisions and undeveloped areas using a 'group' effect that designated whether a site was located in a CD or undeveloped area. I compared model selection results and regression coefficients to determine whether differences between the two site types were supported for each species.

Akaike's Information Criterion corrected for small sample size (AICc) was used to rank and compare occupancy models (Burnham & Anderson 2002). I assessed model fit using a parametric bootstrapping procedure in the unmarked package in R (Fiske & Chandler 2011) and compared the observed Pearson χ^2 statistic for the most general model to the χ^2 statistic from

10,000 simulated bootstrap datasets (MacKenzie & Bailey 2004). For any species that showed overdispersion in the data, I calculated QAICc values by adjusting the model selection results using the estimated overdispersion parameter ($\hat{c}$). I examined the regression coefficients from the highest ranked model to determine the direction and strength of relationship between the design and stewardship factors and the probability of use for each species. I also calculated model-averaged estimates and 95% confidence intervals of site occupancy estimates to compare occupancy estimates between CD and undeveloped areas.

RESULTS

Bird Species Richness

I detected a total of 81 passerine and near-passerine species, with 3,137 detections in 2013 (CD sites only) and 3,356 detections in 2014 (both CD and undeveloped sites). The total number of bird species per site ranged from six to 23 species, with a mean of 13.7 species. Human-sensitive bird species richness ranged from two to 16 species per site, and had a mean of 7.05 species. Human-adapted bird species richness ranged from zero to 15 species per site, and had a mean of 6.65 species. Natural land cover (NATURAL) within 1km was the only design variable that was included in the top model set ($\Delta AIC_c<2$) for human-sensitive bird species richness, and both a linear and a quadratic relationship were included for this variable (Table 3). NATURAL (linear) had a strong positive relationship with human-sensitive species richness (Table 3, Figure 3). The quadratic term for the model that included the quadratic form of NATURAL had low precision, indicating that this effect was less supported than the linear relationship. Housing Density (DENS) within 1km was the only variable included in the top model set for human-adapted bird species richness (Table 3), and the top model had a quadratic relationship of DENS with human-adapted bird species richness. In this model, the richness of human-adapted bird species peaked in the middle of the range of housing densities investigated (Figure 3).

Bird Habitat Use

Of the 81 passerines and near-passerines detected, 16 species met the inclusion criteria and were selected for occupancy modeling; the American Goldfinch (*Spinus tristis*), Barn Swallow (*Hirundo rustica*), Blue-gray Gnatcatcher (*Polioptila caerulea*), Bullock's Oriole (*Icterus bullockii*), Cliff Swallow (*Petrochelidon pyrrhonota*), Common Yellowthroat (*Geothlypis trichas*), Eastern Kingbird (*Tyrannus tyrannus*), European Starling (*Sturnus vulgaris*), House Wren (*Troglodytes aedon*), Lark Sparrow (*Chondestes grammacus*), Lazuli Bunting (*Passerina amoena*), Rock Wren (*Salpinctes obsoletus*), Spotted Towhee (*Pipilo maculatus*), Vesper Sparrow (*Pooecetes gramineus*), Western Kingbird (*Tyrannus verticalis*), and Western Wood-pewee (*Contopus sordidulus*).

For three of the 16 species examined, the best supported model showed a difference in habitat use between the CDs and undeveloped areas (Figure 4). Parameter estimates from the top model show that House Wren habitat use was 7.11 times greater in CD sites than in undeveloped sites, and European Starling habitat use was 6.24 times greater in CD sites. Habitat use by American Goldfinches was 1.57 times greater in the undeveloped sites than the CD sites.

Model selection results indicated that for the majority of bird species (56%) no colonization or extinction was observed between the two seasons. Four species, the American Goldfinch, Cliff Swallow, House Wren, and Vesper Sparrow, had different use between the two seasons with constant rates of extinction or colonization (Appendix 3). Bullock's Orioles and Western Kingbirds had changes in the probability of extinction or colonization depending on the elevation of the site, and colonization by the Rock Wren changed depending on the site's landscape position (i.e., Easting).

Design Factors that Influenced Bird Habitat Use

CD open space habitat use (ψ) was influenced predominantly by design factors for a majority of bird species, and variables that indicated the amount of different natural land cover types (SHRUB, FOREST, GRASS, and NATURAL) in the surrounding landscape matrix were the most predominant factors. The effects of these variables on habitat use (ψ) were included in the top model set (ΔQAICc<2) for 11 of the 16 bird species examined (Table 4, Appendix 3). Ten species had 95% confidence intervals for the regression coefficient (β) that did not overlap zero, which indicates that the influence of these variables on habitat use was well supported for these species. There were a variety of positive and negative responses to increasing natural land cover in the surrounding landscape (Table 4, *Landscape Context*). Two other covariates that indicated the sites position on the landscape were also included in the top model sets for several bird species. The site's landscape position (NORTH, EAST) was included in the top model set for five bird species (Appendix 3). Three species had negative relationships with NORTH, one had a positive relationship with NORTH, and one species also had a positive relationship with EAST (Appendix 3).

The proportion of the CD designated as protected space (PROP) was the second most predominant factor, and was included in the top model set for seven of the 16 bird species examined (Table 4, Appendix 3). Regression coefficients show that habitat use and PROP had strong positive relationships for four bird species (Table 4). Five species included an effect of the total area of the protected open space (AREA) in their top model set (Table 4, Appendix 3), including two species that had well-supported positive relationships with AREA and one species with a well-supported negative relationship. The density of houses surrounding the sampling point (DENS) was included in the top model set for five species (Table 4, Appendix 3). Habitat use by four species increased as housing density in the surrounding landscape increased (Table 4). The perimeter to area ratio of the open space (SHAPE) had little support in the model selection results. It was included in three of the top model sets, but precision was poor in each instance.

Stewardship Factors that Influenced Bird Habitat Use

Among stewardship factors, variables that indicated the local habitat type and quality were by far the best supported, and they were included as an effect on habitat use (ψ) in the top model set for seven out of the 16 species examined (Table 4, Appendix 3). Habitat use by two species was positively related to native and natural vegetation cover types at smaller scales, and two species had negative relationships with these variables (Table 4). Localized disturbances were the next best supported set of stewardship variables. These variables were included in the top model set for seven species (Table 4, Appendix 3). Well-supported relationships were found for three species; two species had negative relationships with localized disturbances, and one species had a positive relationship (Table 4). Variables that indicate resource subsidies were the least supported set of stewardship characteristics. These variables were included in the top model set for three species, and had a negative relationship for one species (Table 4, Appendix 3).

Mammals

Camera traps detected 18 mammal species in the CD subdivisions and undeveloped areas: American black bear (*Ursus americanus*), mountain lion (*Puma concolor)*, bobcat (*Lynx rufus)*, red fox (*Vulpes vulpes)*, striped skunk (*Mephitis mephitis)*, elk (*Cervus canadensis)*, black-tailed prairie dog (*Cynomys ludovicianus*), mule deer (*Odocoileus hemionus)*, white-tailed deer (Odocoileus virginianus), raccoon (*Procyon lotor*), coyote (*Canis latrans)*, cottontail (*Sylvilagus sp.)*, fox squirrel (Sciurus niger), domestic dogs (*Canis familiaris*), cows (*Bos primigenius)*, horses (*Equus ferus caballus*), domestic cats (*Felis* catus) and people. There were a total of 8,636 detections during the three sampling seasons (Table 5).

Mammal Species Richness

The total number of mammal species per site ranged from zero to five species, with a mean of 2.76 species. Human-sensitive mammal species richness ranged from zero to three species per site, and had a mean of 1.02 species. Human-adapted mammal species richness ranged from zero to four species per site, and had a mean of 1.75 species. The proportion of agricultural land cover (AG) within 1km was the only design variable included in the top model set for human-sensitive mammal species richness (ΔAICc<2), and both a linear and a quadratic relationship were included for this variable (Table 6). The model with a linear relationship for AG showed a strong negative relationship with human-sensitive mammal species richness (Table 6). The quadratic term for the quadratic AG model had low precision, indicating that this effect was less supported than the linear relationship. There was considerable model uncertainty in the model set for human-adapted mammal species richness, and seven of the models were within 2AICc units of the best supported model (Table 6). These included a model with a quadratic relationship for traffic volume, proportion of agriculture, presence of non-natural water, total area of the open space, proportion of the CD protected, the null model, and a linear model for traffic. However, precision was poor for each term, which indicates that human-adapted mammal species richness did not have a strong relationship with any of these variables.

Mammal Habitat Use

Elk, black-tailed prairie dog, mule deer, coyote, raccoon, and cottontails met the detection criteria and were included in the occupancy analysis. Species that were not analyzed either did not have sufficient detections for occupancy analysis (e.g., mountain lion, bobcat, black bear, red fox), or were not species of conservation interest (e.g., cow, horse, domestic dog). For four of the six mammal species examined, the best supported model showed no difference in habitat use between sites in the CDs and undeveloped areas (Figure 5). Estimates from the top model show that both coyotes and cottontails had higher estimates of habitat use in CD sites than in undeveloped sites. Habitat use was 1.54 times greater for coyotes and 1.85 times greater for cottontails in the CD sites than in the undeveloped sites.

Several mammals showed different levels of habitat use between seasons, and three species had differences in their dynamic parameters depending on spatial or CD design covariates (Appendix 4). The probability that raccoons would locally colonize a site increased with increasing housing density, while colonization by mule deer increased as the proportion of natural habitat in the surrounding 2km increased. The top models for black-tailed prairie dogs included a negative effect of housing density on the probability of extinction and the top models for cottontails included a positive effect of colonization with increasing elevation. However, 95% confidence intervals for both of these estimates overlapped zero.

Design Factors that Influenced Mammal Habitat Use

CD open space habitat use (ψ) by mammals was predominantly influenced by design factors, and the total area of the open space (AREA) was the most common design factor. Five species included an effect of AREA on habitat use in their top model set (Table 7, Appendix 4), and four of these species had 95% confidence intervals for the regression coefficient (β) that did not overlap zero. Two species had increased habitat use and two species had decreased habitat use with increasing open space area (Table 7). The proportion of the CD designated as open space (PROP) was included in the top model set for 4 species, and had well-supported effects on habitat use for three species (Table 7, Appendix 4). Variables that indicated the proportion of natural land cover types in the surrounding landscape, SHRUB and FOREST, were included in the top model sets for five species (Table 7, Appendix 4). Habitat use by three species had well-supported relationships with these variables (Table 7). The last supported design variable was housing density around the point (DENS), which was included in the top model set for all six mammal species, but the 95% confidence intervals for the estimates overlapped zero for all but two species (Table 7, Appendix 4).

Stewardship Factors that Influenced Mammal Habitat Use

Overall, stewardship variables were not well-supported as factors that influenced mammalian habitat use in CDs. The only stewardship variables that appeared in the top model sets were those that indicated localized disturbances in the open space, and these were important for two species (Table 7, Appendix 4).

DISCUSSION

To successfully preserve diverse and healthy animal communities, CD planners, developers, and landowners need to enhance key design and stewardship factors that promote the persistence of human-sensitive species. By investigating patterns of bird and mammal occurrence in CD open space, this study found that bird and mammal species richness and habitat use were driven predominantly by design characteristics that maximize the natural or undisturbed land area both within and surrounding the development (e.g., proportion of CD preserved, total area of the protected space, proportion of natural land uses at broad scales). Habitat use by birds was also often influenced by local habitat composition and quality, and several bird and mammal species had decreased habitat use in areas with increased localized disturbances such as presence of humans and mowing in the open space. Contrary to several of my hypotheses, birds and mammals did not alter their use of the open space in response to the presence or abundance of resource subsidies such as trash, non-natural water sources, or birdfeeders.

Design Factors

Species richness of human-sensitive bird species, and habitat use for many bird species varied depending on the placement of the CD within a larger landscape of natural or anthropogenic land uses. Landscape context was equally or more important in determining the occurrence and composition of birds than the total area or proportion of the CD preserved as open space. It appears that CDs may be able to function as part of a larger network of undeveloped or protected space, which renders the total area of an individual CD open space less important to many birds. This result was consistent with past studies that have found impacts of landscape-scale land use on passerines, despite their relatively small home ranges (Knick & Rotenberry 1995; Irvin et al. 2013; Lee & Carroll 2014). A study of grassland birds by Vickery et al. (1994) recommended that in order to provide habitat for diverse grassland bird fauna, grassland habitat patches that are approximately 200ha or greater must be preserved. A majority (79%) of the CDs that I examined had a total area of protected space that was less than 200ha, and eight (57%) were smaller than 100ha. In order for sensitive birds to persist in open space of this size, it is likely that they would also need to utilize natural areas in the surrounding landscape.

The proportion of the CD preserved as open space and the total area of the open space also influenced habitat use by a variety of bird species. Cliff Swallows, Common Yellowthroats, Eastern Kingbirds, and Rock Wrens and American Goldfinches, the species that responded positively to the total area and proportion preserved as open space, tend to be sensitive to land conversion due to human development (Guzy & Ritchison 1999; Murphy 1996; Lowther et al. 2000). Several studies on wildlife near housing development have detected a "zone of influence" where species composition is impacted in the area immediately surrounding a house (Bock et al, 1999; Odell et al. 2003; Glennon & Kretser 2013). CD subdivisions with greater proportion of land preserved and densely clustered houses will have more open space that falls outside of each house's zone of influence, and will be more likely to maintain a greater diversity of human-sensitive bird species. The proportion of the area preserved as open space was more important for many species than the area or the shape of the open space, although each of these variables indicates differences in how the habitat may be impacted by housing. It is possible that species are responding more to the proportion of land preserved because this variable better represented the suite of disturbances that would accompany higher levels of housing development on the CD. CDs with a higher proportion of house lots (i.e., lower PROP values) would have multiple disturbances, including people, cars, lawnmowers, traffic, and changed land uses, regardless of the size or shape of the protected area. Interestingly, Cliff Swallows responded positively to both proportion of land preserved and large-scale housing density (3km). This species is an aerial insectivore that has been known to utilize human structures for nesting (Brown & Brown 1995). Perhaps Cliff Swallows take advantage of the nesting opportunities provided by bridges and buildings in landscapes with higher housing densities, but prefer to forage in areas with a high proportion of protected open space, which may have a higher abundance and diversity of insect prey items (Gibbs & Stanton 2001).

The bird species that responded to housing density in the landscape tended to be those that are adapted to living within human-dominated land uses. Human-adapted species richness peaked at intermediate levels of housing density, which is consistent with the "intermediate disturbance hypothesis" and past research on bird species richness patterns in urbanizing areas (Wilson 1990; McKinney 2008). Species richness for human-adapted birds peaked at around 150 houses/km^2 within 1km of the site and then decreased as housing density rose to the highest levels. Several individual bird species also had habitat use responses to housing density, including Bullock's Oriole, European Starling, House Wren, and Cliff Swallow. The majority of these species responded to housing density at large scales (1km or greater), which indicates that the housing in the landscape surrounding the CD is influencing their habitat use more than the density of houses within the CD.

The total area of the CD and the proportion of the CD preserved as protected space were both especially important for mammalian habitat use. Open space area had a positive influence on cottontails, coyote, and raccoon, and negatively impacted mule deer. The proportion of open space preserved had a positive impact on coyotes, but negatively impacted cottontail and mule deer. This result is surprising given that mule deer responded negatively to housing density in our study area. However, CDs with smaller areas and proportions of open space may attract cottontails and mule deer because they contain attractive food sources (Hunt et al. 2014; Kie et al. 2002). It is also possible that these species are taking advantage of a "predator refuge" by congregating in CDs with a small area or proportion of open space that their predators tend to avoid (Hansen et al. 2005). The open space of CDs with smaller proportion of the area preserved could also serve as the last remaining natural corridors in this landscape; mule deer home ranges may thus overlap in these areas as they travel through a matrix with limited movement options (Riley 2006).

Variables that indicated the proportion of different land types at larger scales were also important for mammal species overall; species richness by sensitive mammals decreased as the proportion of agricultural land uses in the landscape increased. Additionally, mule deer and elk were both positively impacted by the proportion of shrubland in the surrounding landscape. Both of these species are large, wide-ranging ungulates that migrate between summer and winter ranges (Nowak 1991). The coyote, another species influenced by landscape context variables, is also relatively large-bodied and wide-ranging (Crooks 2002). Furthermore, mountain lions and black bears were only detected at CD sites that had a high proportion of natural or undeveloped habitat types in the surrounding landscape (an average of 83% natural habitat within 2km). This is considerably larger than the average proportion of natural habitat surrounding the CD sites (32%). The composition of the landscape matrix can determine the probability that an individual animal can move successfully into the habitat patch from another area (Gustafson & Gardner 1996; Fahrig 2001), and large mammals often need especially large areas of habitat to sustain viable populations (Noss et al. 1996). The smaller-bodied species that I examined, cottontails and raccoons, were both positively influenced by the area of the protected space but were not impacted by any landscape-level variables. The total area of the CD open space may be sufficient as the minimum patch size for these species to persist, so they may be less likely to be influenced by land use in the surrounding landscape.

Overall, mammals tended to respond more to changes in housing density at a small scale (less than 500m from the sampling point). These species are more likely to be influenced by the design of the CD and placement of the houses within the development. It also appears that competing factors are driving mammal occurrence across the housing density gradient. For example, mule deer tended to avoid open space areas associated with residential development

(Polfus & Krausman 2012), whereas raccoons use these habitats with greater frequency. This finding is consistent with the "mesopredator release" hypothesis, in which the absence of top predators in these areas can cause an increased abundance and use by small- to mid- size species such as the raccoon (Crooks & Soulé 1999; Ritchie & Johnson 2009).

Stewardship Factors

American Goldfinches, Barn Swallows, Lark Sparrows, and Western Kingbirds were all influenced by the local habitat quality and composition of the open space, which supports the second prediction by Lenth et al. (2006). This finding is also consistent with evidence that suggests that a growing dominance of exotic vegetation in Boulder County has led to the decline of bird species endemic to short grass prairie systems (Jones & Bock 2002). In fact, many of the CD sites I sampled had fairly sparse native plant cover. This could be caused by invasive non-native plants that have escaped from home lots and invaded the open space areas (Pimental et al. 2001), plant invasions attributable to grazing (Alejandro et al. 2010), as well as a lack of expertise, funding or interest in long-term open space management to maintain native vegetation (Feinberg et al. 2015).

Only a few species were impacted by local disturbances in and around the open space. Both Cliff Swallows and mule deer had decreased habitat use in areas with a high traffic volume. Past studies have shown that high levels of anthropogenic noise, light, and other visual disturbances can decrease wildlife occurrence and cause changes in behavior (Slabbekoorn & Ripmeester 2008; Bayne et al. 2008; Barber et al. 2010; Chan & Blumstein 2011). Traffic can also cause direct mortalities (Reijnen et al. 1995) and noise may decrease an animal's ability to make important biological decisions about food selection and predator detection, and decrease its survival rate (Chan & Blumstein 2011).

Lazuli Bunting had decreased occurrence in areas where humans used the open space, and mule deer had decreased occurrence where domestic dogs were detected in the open space. Several studies have found increases in wildlife flight and vigilance activities or changes in habitat use due to direct human disturbances such as recreational use (Mainini et al. 1993; George & Crooks 2006; Reed & Merenlender 2011). Wildlife will often spend more time on vigilance behaviors with increased human presence in an area, and spend less time on other important activities such as foraging (Burger 1994). These types of behavioral changes could discourage human-sensitive species from using these sites.

I also predicted that human-adapted birds and mammals would be attracted to resource subsidies available in proximity to human habitation, but this hypothesis was not supported. It is possible that the overall effect of housing at a broad scale has a greater influence on this species than any changes in specific resource subsidies between sites. However, because I used visual observations in the vicinity of the sampling point to record resource subsidies in the surrounding area, subsidies that were hidden from view were not included in this metric. I was also unable to measure the volume or temporal availability of resource subsidies.

Habitat Use in CD and Undeveloped Sites

A surprising result of this study was that there were very few differences in habitat use between sites in the undeveloped areas and the CD subdivisions. Of the species that had differences in occupancy between the two types of sites, most showed higher use of sites in CD subdivisions than sites in undeveloped areas. These findings are not consistent with those of Lenth et al. (2006), which documented decreased abundance of birds and mammals in the CD subdivisions when compared to undeveloped areas. It is possible that this discrepancy may be due to the different state variables examined; this study used habitat use, whereas Lenth et al.

examined abundance (Lenth et al. 2006). It could also be due in part to the list of species that I analyzed; all of the species were selected from those that had sufficient detections within the CD sites to analyze using occupancy modeling. Finally, it is possible that differences in site selection were responsible for these differences. The undeveloped areas that I used were both similar in size and landscape placement to the CD areas, while the Lenth study examined undeveloped areas that were an average of 400ha larger than the CDs (Lenth et al. 2006). The similarities that I found indicate that, if CDs are large enough or located within a matrix of undeveloped, natural land, they can provide wildlife habitat that supports similar habitat use patterns as protected areas that lack housing development.

Scope of Study

It is important to acknowledge that there are limitations when using occupancy modeling and species richness as metrics of conservation success. These approaches do not provide information on more fine-scale ecological processes like survival and reproductive success. It is possible that animals may use habitat in CDs, but experience decreased fitness or reproductive success over time, rendering the area an "ecological trap" (Dwernychuk & Boag 1972). Ecological traps have been observed primarily in habitats that are disturbed or modified by human activities (Batten 2004), so it is possible that the open spaces of certain CDs fit this category. I recommend that future ecological research in CDs should focus on measuring population dynamics to fully understand how successful CDs are at preserving habitat for birds and mammals.

It is possible that aspects of the study's design may have affected the prevalence of design variables over stewardship variables as important factors influencing habitat use of CD open space. I was able to select CD study areas with a range of design characteristics, such as open space size and housing density. However, without prior information regarding the stewardship characteristics of CDs in the area, I was unable to incorporate a broad range of values for these factors into the initial study design. It is possible that the effects of the stewardship characteristics on habitat use were found to be less important overall because the variation in values was too low, or the majority of sites fell at the low end of the spectrum. For example, 61% of the CD sites had 10% native shrub and forb cover or less, and resource subsidies only occurred in 10-20% of the sites. It is also likely that the optimal CD characteristics differ between taxonomic groups. Previous studies have found that bees and butterflies in exurban and urban areas are predominantly influenced by vegetation and local habitat features (McIntyre & Hostetler 2001; Niell et al. 2007). This study only examined birds and mammals, which often have large home ranges or the ability to disperse over long distances. Other taxonomic groups, such as insects, small mammals, reptiles, and amphibians, may be more heavily influenced by CD stewardship factors. In order to attain a more comprehensive understanding of the conservation value of CDs for plant and animal communities, future research should examine CD habitat relationships for species in other taxonomic groups.

Conservation Application

The findings of this study reveal several key design and stewardship factors that strongly influence the conservation value of CD open space for birds and mammals. I recommend the following actions to improve CD as a private land conservation strategy (Table 8). In order to ensure that CDs preserve sufficiently large areas of open space or are adjacent to other natural space or protected areas, county planning agencies should consider adding language to CD ordinances that stipulates minimum area requirements, minimum proportion of the land parcel to be preserved as open space, and guidelines to encourage adjacency of the open space to other protected lands. Different species responded differently to these three factors, so the strategy used may differ depending on the conservation objectives of the region. However, the total number of sensitive bird and mammal species was driven by the land use in the surrounding area, so a strategy that emphasizes encouraging adjacency to other protected or undeveloped land may have a greater overall effect on increasing the ability for a CD to provide habitat for many sensitive species. Another strategy would be to develop regional conservation plans to identify important areas for conservation at a larger scale. CDs could then be placed strategically in high-priority areas that are connected to a larger reserve network. However, because CDs inherently include housing, it is also possible that they could fragment established protected areas rather than buffering them from human disturbances (Mockrin et al. In Review).

It is also important to ensure that CD protected open space consists of vegetation that provides high quality wildlife habitat. To achieve this goal, ordinances could require an ecological site assessment to identify important ecological areas that should be protected before the design or construction of a development. HOA rules or education initiatives could also discourage CD landowners from landscaping with invasive exotic plants that may colonize the open space. Finally, requiring ecologically informed management plans, and ensuring sufficient funding to implement stewardship activities could ensure that the open space continues to provide high-quality habitat for targeted species over the long-term.

Conclusion

This study demonstrates that CDs with particular design and stewardship characteristics can mitigate some of the negative impacts of exurban housing development on wildlife and provide effective private land conservation for birds and mammals. Currently, land is being protected at half the rate that it is being converted by human development (Aldrich & Wyerman

2006), due in part to the lack of funding for land acquisition and preservation. CD provides a variety of social and economic benefits, including increased home values, scenic views, marketing and sales advantages, and reduced costs associated with infrastructure and storm water management (Milder & Clark 2011; Sullivan 1994; Hannum et al. 2012). These advantages may incentivize the continued use of CD as housing needs grow, essentially creating conservation projects that fund themselves. My research identifies ways to enhance the biodiversity value of CDs, an increasingly common tool for conserving private lands.

TABLES

Table 1. Site-specific design and stewardship variables used to assess bird and mammal occupancy in 14 CD subdivisions and 4 undeveloped areas in Boulder and Larimer counties, CO.

Variable	Description (units)
Design Variables	
Open Space Size and Configuration	
AREA	Total area of protected open space (km^2)
SHAPE	Perimeter length to area ratio of protected open space (m/km^2)
PROP	Proportion of the CD designated as protected space vs. home lots (%)
Housing Development	
DENS†	Density of houses in surrounding landscape at various buffer distances ($dwelling/km^2$)
Landscape Context (obtained from USGS Southwestern Regional GAP Analysis database)	
NATURAL†	Percentage of natural, undeveloped and nonagricultural land use in surrounding landscape at various buffer distances (%)
SHRUB†	Percentage of shrubland in surrounding landscape at various buffer distances (%)
FOREST†	Percentage of forest in surrounding landscape at various buffer distances (%)
GRASS†	Percentage of grassland in surrounding landscape at various buffer distances (%)
AG†	Percentage of agricultural land in surrounding landscape at various buffer distances (%)
Stewardship Variables	
Habitat Composition	
NATIVE	Percent cover of native shrubs and forbs within 10m of the point; average of 3 $1m^2$ quadrat surveys (%)
SHRUB	Percent cover of shrubs within 200m or 500m of the point (%)
FOREST	Percent cover of trees within 200m or 500m of the point (%)
GRASS	Percent cover of grassland within 200m or 500m of the point (%)
NATURAL	Percent cover of all natural land cover (excludes agriculture and impervious surface) within 200m or 500m of the point (%)
Local Disturbances	
COW	Presence (birds) or relative activity (mammals) of cows within 200m of the sampling point (images/night)
DOG	Presence (birds) or relative activity (mammals) of domestic dogs within 200m of the sampling point (images/night)
HUMAN	Presence (birds) or relative activity (mammals) of humans within 200m of the sampling point (images/night)
MOW	Presence or absence of mowing within 100m of sampling point (binary: [0,1])
TRAFFIC	Traffic volume within 200m of sampling point (vehicles/minute)
LIGHT	Light sources (e.g. porch lights, streetlamps) within 200m of sampling point (count)
Resource Subsidies	
TRASH§	Trashcans or dumpsters within 200m of sampling point (count)
BRDFEED*	Bird feeders within 200m of sampling point (count)
NNWATER	Non-natural water sources within 200m of sampling point (count)
Other Variables	
ELEV	Elevation of the sampling point (m)
CANCOV	Percent cover of tree canopy at sampling point (%)
EASTING	The sampling points eastward-measured distance (m)
NORTHING	The sampling points northward-measured distance (m)

†Buffer radius of 0.2km, 0.5km, 1km, 2km, 3km or average species home range size tested for each species (“HR”)
§Variable included in model sets for mammals only
*Variable included in model sets for birds only

Table 2. Survey and site-specific variables used to assess bird and mammal detection probability in 14 CD subdivisions and 4 undeveloped areas in Boulder and Larimer counties, CO.

Variable	Description (units)
JDate	Date of point count survey, or mid-point of camera trap sampling period
Time	Time of point count survey
Wind	Code indicating wind speed at time of point count survey
Cloud	Cloud cover at time of point count survey (%)
Rain	Code indicating precipitation at time of point count survey
Camera	Brand of remotely-triggered camera
CANCOV	Percent cover of tree canopy at sampling point (%)

Table 3. Best supported linear regression models (within 2 ΔAICc) for observed species richness of human-sensitive and human-adapted bird species groups in relation to CD design and stewardship characteristics. The AICc values, ΔAICc values, residual deviance, regression coefficient estimates and standard errors are shown for each model.

Model	AICc	ΔAICc	Residual Deviance	Regression Coefficient (SE)
Human-sensitive Bird Species Richness				
NATURAL1km	433.30	0.05	68.43	+0.99(0.12)
NATURAL1km+NATURAL1km^2	433.25	0	66.38	+1.93(0.68) -0.79(0.55)
Human-adapted Bird Species Richness				
DENS1km+DENS1km^2	446.84	0	87.02	+0.011(0.003) -0.00003(0.00001)

Table 4. Regression coefficients (β) and standard errors for design and stewardship covariates appearing in the top models (within 2 ΔAICc) explaining habitat use (ψ) of birds in CD open space. Estimates of the regression coefficients (β) from the top model that included the covariate are presented, and estimates with confidence intervals that do not overlap 0 are presented in bold.

	Design Variables					Stewardship Variables		
Species	*Area*	*Shape*	*Proportion Protected*	*Housing Density*	*Landscape Context*	*Habitat Composition*	*Local Disturbance*	*Resource Subsidies*
Human-sensitive								
American Goldfinch	**0.87(0.42)**	106.1(54.8)		3K: 0.01(0.006)		**NATIVE: 5.87(2.17)**		
Blue-gray Gnatcatcher					SHRUB 2K: 96.01 (79.5)	NATIVE: 122.2(117.2)		
Lark Sparrow	3.04(1.56)					**SHRUB200m: 52.66(26.2)**		
Lazuli Bunting					**SHRUB 3K: 55.06(17.4)**		**HUMAN: -8.24(3.15)**	
Rock Wren			**6.04(0.02)**		**SHRUB 3K: 16.45(0.19)**			
Spotted Towhee			0.58(5.08)		**SHRUB 1K: 46.03(11.9)**	NATIVE: 10.87(6.60)	HUMAN: -2.43(1.51)	
Vesper Sparrow			-8.87(0.02)		**FOREST1K: -26.68(5.3)**			
Western Kingbird						**FOREST 200m: -15.69(0.031)**		BRDFEED: -0.80(0.45)
Western Wood-pewee					**FOREST1K: 17.89(4.46)**		TRAFFIC: -5.58(4.07)	
Human-adapted								
Barn Swallow	0.71(0.51)	706.5(537.8)	6.88(3.65)			**NATURAL500: 5.94(1.94)** NATIVE: -7.7(5.65)	COW: 1.43(1.08)	NNWATER: 0.92(0.53)
Bullock's Oriole				**3K: 0.04(0.02)**	**GRASS 2K: -4.01(2.04)**			
Cliff Swallow	**0.71(0.003)**	-177.1(63.3)	**6.32(2.38)**	**3K: 0.07(0.001)**	**NATURAL3K: 4.83(0.03)**		**MOW: -2.25(0.57) TRAFFIC: -1.12(0.54)**	**NNWATER: -1.1(0.5)**
Common Yellowthroat	**-1.26(0.71)**		**14.16(5.45)**			NATIVE: -10.75(6.22)	**MOW: 4.19(1.19)**	
Eastern Kingbird			**19.12(9.44)**		**SHRUB 3K: -22.27(9.99)**			
European Starling				**500m: 0.05(0.02)**	**SHRUB 1K: -24.98(5.98)**		TRAFFIC: 1.63(1.65)	
House Wren				**200m: 0.02(0.01)**	**FOREST 1K: 5.75(1.28)**			

Table 5. The number of detections of mammal species captured by wildlife cameras and the proportion of sites (n=71) where the species was detected.

Species	Latin Name	Number of Images	Proportion of Sites Observed (Naïve occupancy estimates)
Human-sensitive			
Coyote	*Canis latrans*	412	0.66
Elk	*Cervus canadensis*	554	0.17
Bobcat	*Lynx rufus*	7	0.08
American Black Bear	*Ursus americanus*	6	0.06
Mountain Lion	*Puma concolor*	1	0.01
Human-adapted			
Cottontail	*Sylvilagus sp.*	1366	0.51
Mule Deer	*Odocoileus hemionus*	773	0.42
Black-tailed Prairie Dog	*Cynomys ludovicianus*	1689	0.18
Raccoon	*Procyon lotor*	123	0.18
Striped Skunk	*Mephitis mephitis*	10	0.10
White-tailed Deer	*Odocoileus virginianus*	33	0.10
Red Fox	*Vulpes vulpes*	13	0.08
Fox Squirrel	*Sciurus niger*	10	0.03
Domestic			
Human	*Homo sapiens*	64	0.21
Domestic Dog	*Canis familiaris*	44	0.11
Cow	*Bos primigenius*	3516	0.06
Horse	*Equus ferus caballus*	13	0.03
Domestic Cat	*Felis catus*	2	0.03

Table 6. Best supported linear regression models for observed species richness of human-sensitive and human-adapted mammal species groups in relation to CD design and stewardship characteristics. The AICc values, ΔAICc values, residual deviance, and regression coefficient estimates are shown for each model.

Model	**AICc**	**ΔAICc**	**Residual Deviance**	**Regression Coefficient (SE)**
Human-sensitive Mammal Species Richness				
Agriculture within 1km	125.29	0.00	26.16	-1.17(0.47)
Agriculture within 1km (Quadratic)	125.75	0.46	24.62	0.87 (1.73) -2.93(2.40)
Human-adapted Mammal Species Richness				
Traffic Volume (Quadratic)	165.5	0.0	37.90	-0.71(0.37) 0.05(0.03)
Grass within 2km	166.6	1.1	41.01	1.34(0.80)
Non-natural Water Sources	167.1	1.6	41.53	-0.36(0.25)
Area of the Open Space	167.4	1.9	41.76	0.001(0.0007)
Proportion of CD as Open Space	167.4	1.9	41.77	1.26(0.88)
Null model	167.5	2.0	43.87	-
Traffic Volume	167.5	2.0	41.93	-0.11(0.10)

Table 7. Regression coefficients (β) and associated standard errors for covariates appearing in the top models (within 2 ΔAICc) explaining habitat use (ψ) patterns of mammals in CD open space. Estimates of effects with confidence intervals that do not overlap 0 are presented in bold.

	Design Variables					Stewardship Variables		
Species	*Area*	*Shape*	*Proportion*	*Housing Density*	*Landscape Context*	*Habitat Composition*	*Local Disturbances*	*Resource Subsidies*
Human-sensitive								
Coyote	**1.61(0.79)**		**6.91(3.16)**	200m: 0.07(0.04)	**FOREST 3K:** **-4.79(1.69)**			
Elk			15.56(10.7)	500m: -0.09(0.07)	**SHRUB 1K:** **17.02(8.62)**			
Human-adapted								
Black-tailed Prairie Dog	-0.49(0.45)			500m: -0.02(0.03)	FOREST1K: -34.82(22.6)		DOG: 16.71(13.8) COW: -0.47(1.32)	TRASH: 0.92(0.74)
Cottontail	**0.36(0.18)**		**-4.33(1.54)**	HR§: -0.01(0.008)	AG3K: 1.41(0.84)			NNWATER: -0.67(0.52)
Mule Deer	**-0.04(0.01)**		**-3.08(0.01)**	**1K:** **-0.003(0.00002)**	**SHRUB 1K:** **14.40(3.29)**		**TRAFFIC:** **-0.12(0.01)** **DOG:** **-1.50(0.02)** COW: -0.03(0.02)	
Raccoon	**0.30(0.01)**			**3K:** **0.007(0.00003)**	SHRUB 2K: -4.41(5.3)		**LIGHT:** **0.23(0.002)**	

§HR indicates that the covariate was scaled to the species average home range size

Table 8. Important findings and recommendations that emerged from this study that could improve CD's ability to provide habitat for sensitive wildlife species, and a portfolio of strategies to help CD achieve those goals.

Study Finding	Recommendation	Strategies
The majority of species influenced by total area of the open space reached 50% probability of use at CD sites with 150ha of protected open space.	Protect a large area (at least 150ha) of open space	• Minimum area requirements included in CD ordinances
Most birds influenced by PROP did not exceed 0% probability of use until 70-75% of the CD was preserved as protected open space. Coyote reached 50% probability of use at 70% PROP.	Preserve a high proportion (at least 80%) of the CD as protected space	• Requirements for a minimum proportion of area protected included in CD ordinances
63% of birds and 33% of mammals were influenced by natural land types in the surrounding landscape matrix, and most reached 50% probability of use at 30% natural land cover.	Locate CDs in areas adjacent to other natural spaces or protected areas (at least 30% natural land cover in surrounding 1km)	• Create regional conservation plans and design CD protected areas to preserve high priority land • Encourage adjacency with other protected land
Local habitat quality and composition of vegetation in the open space was the most predominant stewardship factor that influenced bird habitat use of CD open space, and most species reached 50% probability of use at 20% native vegetation cover.	Preserve native plants in open space (above 20% native cover) and vegetative structure such as shrubs and trees	• Require ecological site assessments prior to CD design • Use HOA rules or education initiatives to discourage CD landowners from landscaping with exotic invasive plants • Create long-term management plans for open space and provide continued funding

FIGURES

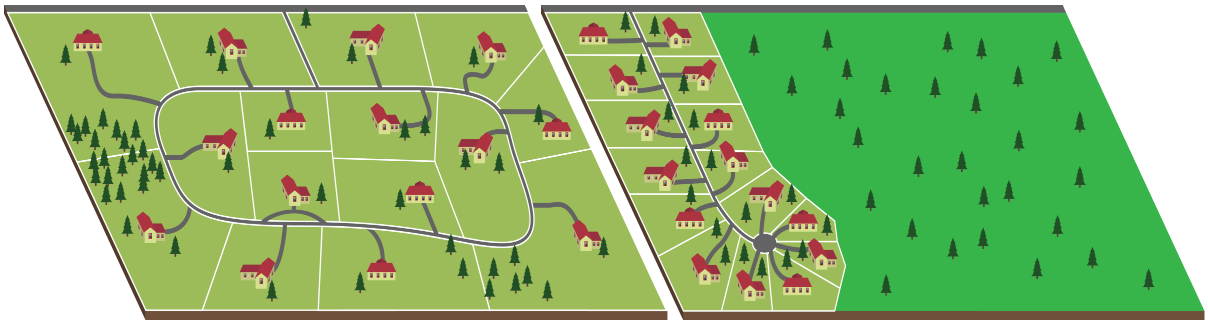

Fig 1. A land parcel developed as a traditional exurban subdivision (left) has houses distributed at a low density across the entire property. A conservation development subdivision (right) clusters houses in a portion of the parcel while preserving the remaining land, including the most ecologically valuable areas, as protected open space (Figure by Sterling Moody).

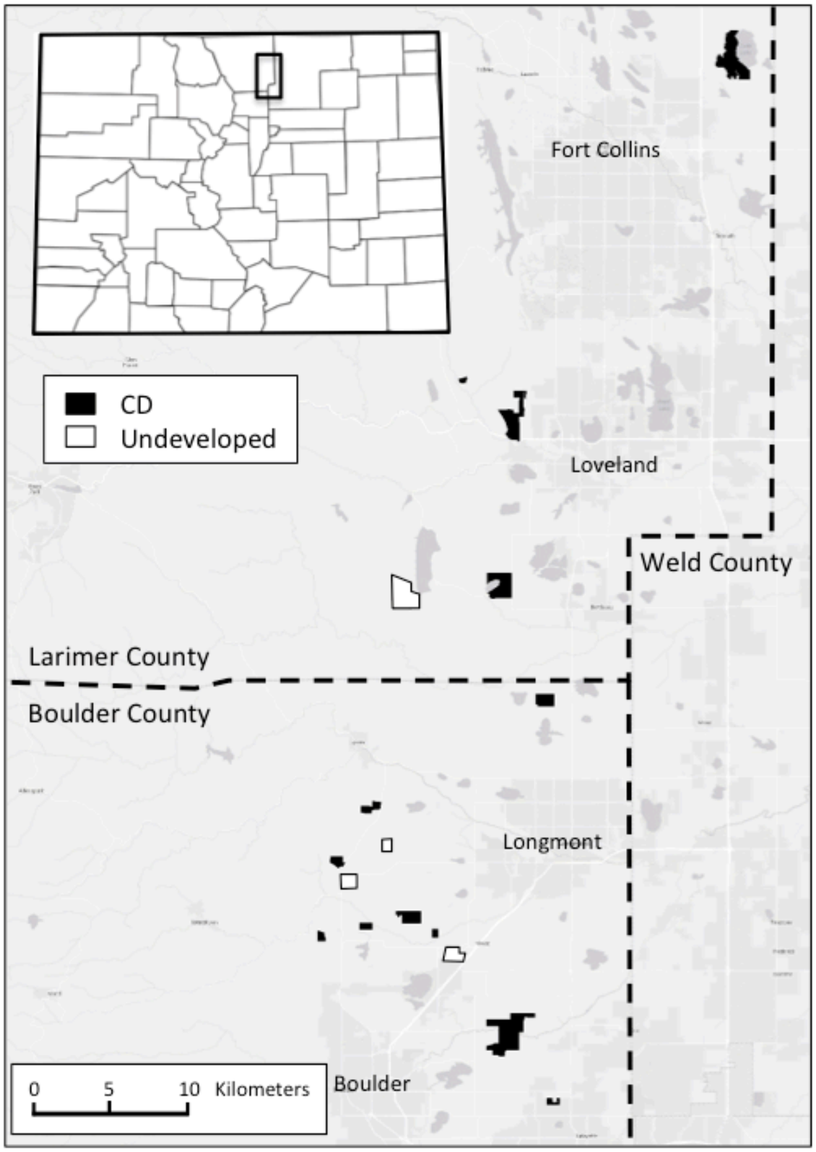

Fig. 2. Study area locations in Boulder County and Larimer County, Colorado.

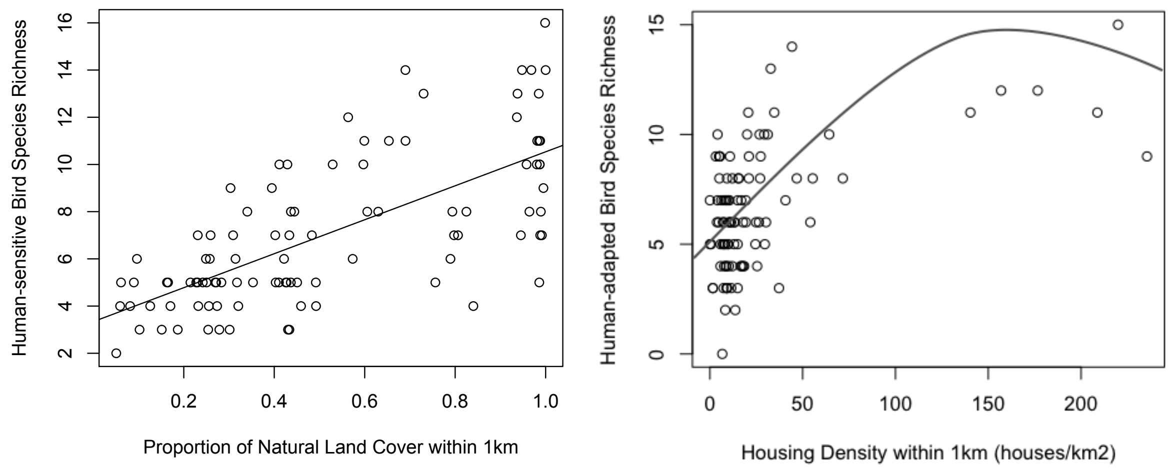

Fig. 3. Relationship between human-sensitive bird species richness and the proportion of natural land cover within 1km (left), and human-adapted bird species richness and housing density within 1km (right) based on the best supported regression models.

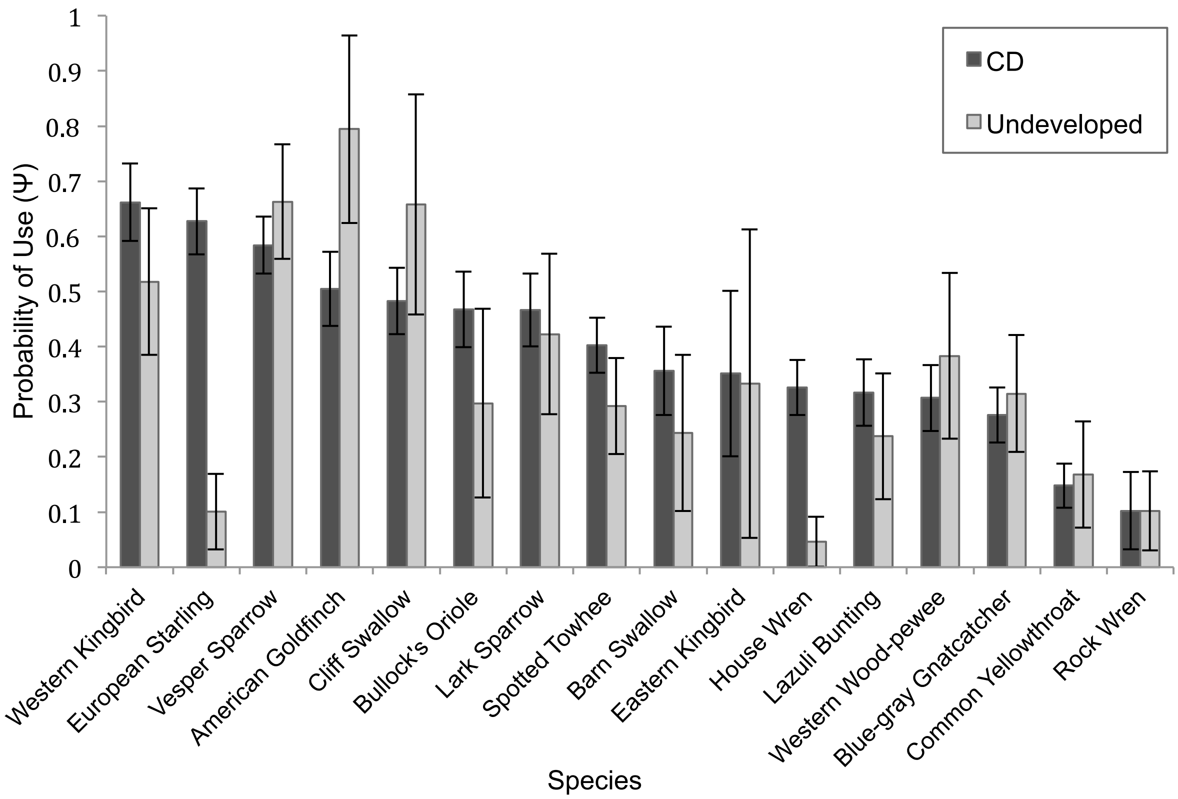

Fig. 4. Probability of use by bird species in CD and undeveloped sites. Predicted values were generated from separate single-species occupancy analysis for each species. 95% confidence intervals around each estimate are shown.

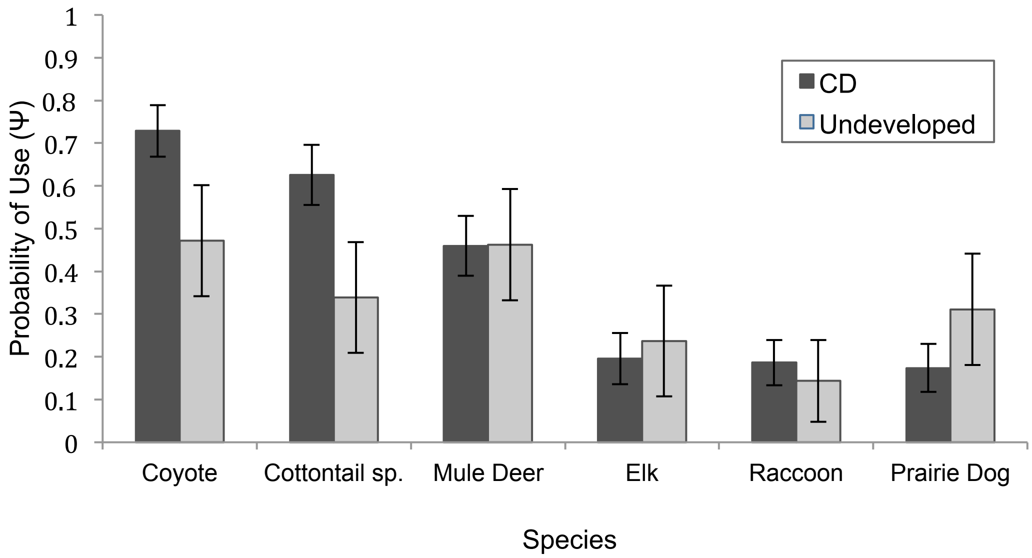

Fig. 5. Probability of use by mammal species in CD and undeveloped sites. Predicted values were generated from separate single-species occupancy analysis for each species. 95% confidence intervals around each estimate are shown.

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APPENDICES

Appendix 1. The classification of each detected bird species into human-adapted and human-sensitive species richness groups.

Species	Latin Name	Species Richness Group	Reference
American Crow	*Corvus brachyrhynchos*	Human-adapted	Chace and Walsh 2006
American Robin	*Turdus migratorius*	Human-adapted	Odell et al. 2001
Barn Swallow	*Hirundo rustica*	Human-adapted	Chace and Walsh 2006
Black-billed Magpie	*Pica hudsonia*	Human-adapted	Odell et al. 2001
Belted Kingfisher	*Megaceryle alcyon*	Human-adapted	Rottenborn 1999
Brown-headed Cowbird	*Molothrus ater*	Human-adapted	Odell et al. 2001
Blue Jay	*Cyanocitta cristata*	Human-adapted	Chace and Walsh 2006
Brewer's Sparrow	*Spizella breweri*	Human-adapted	Chace and Walsh 2006
Bullock's Oriole	*Icterus bullockii*	Human-adapted	Odell et al. 2001
Cassin's Sparrow	*Peucaea cassinii*	Human-adapted	Maestas et al. 2003
Cliff Swallow	*Petrochelidon pyrrhonota*	Human-adapted	Bonier et al. 2007
Common Grackle	*Quiscalus quiscula*	Human-adapted	Rottenborn 1999
Common Raven	*Corvus corax*	Human-adapted	Chace and Walsh 2006
Common Yellowthroat	*Geothlypis trichas*	Human-adapted	Bonier et al. 2007
Eastern Kingbird	*Tyrannus tyrannus*	Human-adapted	Chace and Walsh 2006
Empidonax Flycatcher	*Empidonax Sp.*	Human-adapted	Bonier et al. 2007
Grasshopper Sparrow	*Ammodramus savannarum*	Human-adapted	Odell et al. 2001
Horned Lark	*Eremophila alpestris*	Human-adapted	Chace and Walsh 2006
House Wren	*Troglodytes aedon*	Human-adapted	Chace and Walsh 2006
Killdeer	*Charadrius vociferus*	Human-adapted	Odell et al. 2001
Lark Bunting	*Calamospiza melanocorys*	Human-adapted	Lenth et al. 2006
Mourning Dove	*Zenaida macroura*	Human-adapted	Odell et al. 2001
Northern Waterthrush	*Parkesia noveboracensis*	Human-adapted	Chace and Walsh 2006
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	Human-adapted	Chace and Walsh 2006
Pine Siskin	*Carduelis pinus*	Human-adapted	Rottenborn 1999

Red-winged Blackbird	*Agelaius phoeniceus*	Human-adapted	Chace and Walsh 2006
Say's Phoebe	*Sayornis saya*	Human-adapted	Lenth et al. 2006
American Goldfinch	*Spinus tristis*	Human-sensitive	Rottenborn 1999
Black-capped Chickadee	*Poecile atricapillus*	Human-sensitive	Odell et al. 2001
Blue-gray Gnatcatcher	*Polioptila caerulea*	Human-sensitive	Odell et al. 2001
Black-headed Grosbeak	*Pheucticus melanocephalus*	Human-sensitive	Odell et al. 2001
Blue Grosbeak	*Passerina caerulea*	Human-sensitive	Chace and Walsh 2006
Bobolink	*Dolichonyx oryzivorus*	Human-sensitive	Chace and Walsh 2006
Broad-tailed Hummingbird	*Selasphorus platycercus*	Human-sensitive	Maestas et al. 2003
Canyon Wren	*Catherpes mexicanus*	Human-sensitive	Ruth et al. 2000
Chipping Sparrow	*Spizella passerina*	Human-sensitive	Crooks et al. 2004
Chimney Swift	*Chaetura pelagica*	Human-sensitive	Chace and Walsh 2006
Dark-eyed Junco	*Junco hyemalis*	Human-sensitive	Crooks et al. 2004
Downy Woodpecker	*Picoides pubescens*	Human-sensitive	Chace and Walsh 2006
Eurasian Collard Dove	*Streptopelia decaocto*	Human-sensitive	Hansen and Urban 1992
European Starling	*Sturnus vulgaris*	Human-sensitive	Odell et al. 2001
Green-tailed Towhee	*Pipilo chlorurus*	Human-sensitive	Chace and Walsh 2006
Hairy Woodpecker	*Leuconotopicus villosus*	Human-sensitive	Bonier et al. 2007
House Finch	*Haemorhous mexicanus*	Human-sensitive	Bonier et al. 2007
House Sparrow	*Passer domesticus*	Human-sensitive	Lenth et al. 2006
Lark Sparrow	*Chondestes grammacus*	Human-sensitive	Crooks et al. 2004
Lazuli Bunting	*Passerina amoena*	Human-sensitive	Jones and Bock 2002
Lesser Goldfinch	*Spinus psaltria*	Human-sensitive	Crooks et al. 2004
Lincoln's Sparrow	*Melospiza lincolnii*	Human-sensitive	Chace and Walsh 2006
Mountain Bluebird	*Sialia currucoides*	Human-sensitive	Rottenborn 1999
Mountain Chickadee	*Poecile gambeli*	Human-sensitive	DesGranges and Morneau 2010
Northern Flicker	*Colaptes auratus*	Human-sensitive	Bonier et al. 2007
Olive-sided Flycatcher	*Contopus cooperi*	Human-sensitive	Golet et al. 2001
Plumbeous Vireo	*Vireo plumbeus*	Human-sensitive	Hansen and Urban 1992
Pygmy Nuthatch	*Sitta pygmaea*	Human-sensitive	Bonier et al. 2007

Ruby crowned Kinglet	*Regulus calendula*	Human-sensitive	Odell et al. 2001
Red Crossbill	*Loxia curvirostra*	Human-sensitive	Raphael et al. 2001
Rock Dove	*Columba livia*	Human-sensitive	DesGranges and Morneau 2010
Rock Wren	*Salpinctes obsoletus*	Human-sensitive	Marzluff 2005
Savannah Sparrow	*Passerculus sandwichensis*	Human-sensitive	Maestas et al. 2003
Song Sparrow	*Melospiza melodia*	Human-sensitive	Chace and Walsh 2006
Spotted Towhee	*Pipilo maculatus*	Human-sensitive	Jones and Bock 2002
Stellar's Jay	*Cyanocitta stelleri*	Human-sensitive	Crooks et al. 2004
Townsend's Solitaire	*Myadestes townsendi*	Human-sensitive	Odell et al. 2001
Tree Swallow	*Tachycineta bicolor*	Human-sensitive	Chace and Walsh 2006
Vesper Sparrow	*Pooecetes gramineus*	Human-sensitive	Hall et al. 1997
Violet-green Swallow	*Tachycineta thalassina*	Human-sensitive	Marzluff 2005
Virginia Warbler	*Oreothlypis virginiae*	Human-sensitive	Lenth et al. 2006
White-breasted Nuthatch	*Sitta carolinensis*	Human-sensitive	Rottenborn 1999
Western Kingbird	*Tyrannus verticalis*	Human-sensitive	Odell et al. 2001
Western Meadowlark	*Sturnella neglecta*	Human-sensitive	Rottenborn 1999
Western Scrub Jay	*Aphelocoma californica*	Human-sensitive	Rottenborn 1999
Western Tanager	*Piranga ludoviciana*	Human-sensitive	Chace and Walsh 2006
Willow Flycatcher	*Empidonax traillii*	Human-sensitive	Crooks et al. 2004
Wilson's Warbler	*Cardellina pusilla*	Human-sensitive	Rottenborn 1999
Wood Thrush	*Hylocichla mustelina*	Human-sensitive	Chace and Walsh 2006
Western Wood-pewee	*Contopus sordidulus*	Human-sensitive	DesGranges and Morneau 2010
Yellow-breasted Chat	*Icteria virens*	Human-sensitive	Chace and Walsh 2006
Yellow Warbler	*Setophaga petechia*	Human-sensitive	Chace and Walsh 2006
Yellow-rumped Warbler	*Setophaga coronata*	Human-sensitive	Beachy 2002

Appendix 2. The classification of each detected mammal species into human-adapted and human-sensitive species richness groups.

Species	Latin Name	Species Richness Group	Reference
Black-tailed Prairie Dog	*Cynomys ludovicianus*	Human-adapted	Magle and Crooks 2009
Cottontail	*Sylvilagus sp.*	Human-adapted	Goad et al. 2014
Fox Squirrel	*Sciurus niger*	Human-adapted	McCleary 2009
Mule Deer	*Odocoileus hemionus*	Human-adapted	Goad et al. 2014
Raccoon	*Procyon lotor*	Human-adapted	Prange and Gehrt 2004
Red Fox	*Vulpes vulpes*	Human-adapted	Goad et al. 2014
Striped Skunk	*Mephitis mephitis*	Human-adapted	Prange and Gehrt 2004
White-tailed Deer	*Odocoileus virginianus*	Human-adapted	Adams et al. 2005
American Black Bear	*Ursus americanus*	Human-sensitive	Mattson 1990
Bobcat	*Lynx rufus*	Human-sensitive	Goad et al. 2014
Coyote	*Canis latrans*	Human-sensitive	Goad et al. 2014
Elk	*Cervus canadensis*	Human-sensitive	Goad et al. 2014
Mountain Lion	*Puma concolor*	Human-sensitive	Crooks 2002

Appendix 3. Top model set (ΔQAICc≤2) of occupancy model selection results for habitat use by a subset of bird species detected in the CD sites. The number of parameters in the models (*K*), the model weights (*w*), and the deviance (Dev.) are also shown. When the dynamic parameters (γ or ε) are not given in the model name, the parameters have been set equal to zero.

Model	***K***	**QAICc**	**ΔQAICc**	***w***	**Dev.**
Human-sensitive					
American Goldfinch					
ψ (AREA + DENS3K) γ (.) p(JDate + CANCOV)	7	240.28	0.00	0.08	225.68
ψ (EAST + NATIVE) γ (.) p(JDate + CANCOV)	7	240.67	0.39	0.07	226.06
ψ (AREA * DENS3K) γ (.) p(JDate + CANCOV)	8	241.33	1.05	0.05	224.55
ψ (AREA + NATIVE) γ (.) p(JDate + CANCOV)	7	241.44	1.17	0.04	226.85
ψ (AREA + SHAPE) γ (.) p(JDate + CANCOV)	7	241.59	1.31	0.04	226.99
ψ (AREA) γ (.) p(JDate + CANCOV)	6	241.80	1.52	0.04	229.35
ψ (EAST * NATIVE) γ (.) p(JDate + CANCOV)	8	242.02	1.73	0.03	225.24
Blue-gray Gnatcatcher					
ψ (SHRUB2K + NATIVE) p(JDate)	5	222.09	0.00	0.71	211.43
Lark Sparrow					
ψ (AREA + SHRUB200) p(Wind + CANCOV)	6	189.01	0.00	0.32	176.08
ψ (SHRUB200 + NORTH) p(Wind + CANCOV)	6	190.52	1.50	0.15	177.58
Lazuli Bunting					
ψ (SHRUB2K + HUMN) p(Time + JDate + Cloud)	7	161.26	0.00	0.25	146.00
ψ (SHRUB2K * HUMN) p(Time + JDate + Cloud)	8	161.35	0.09	0.24	143.71
Rock Wren					
ψ (SHRUB2K + PROP) γ (EAST) p(Cloud + Time)	8	184.07	0.00	0.15	167.30
ψ (SHRUB2K) γ (EAST) p(Cloud + Time)	7	185.05	0.98	0.09	170.45
Spotted Towhee					
ψ (SHRUB1K + NATIVE) p(Time +CANCOV+JDate+Cloud)	8	223.72	0.00	0.11	206.08
ψ (SHRUB1K * PROP) p(Time+CANCOV+JDate +Cloud)	9	224.19	0.47	0.08	204.12
ψ (SHRUB1K) p(Time + CANCOV + JDate + Cloud)	7	224.25	0.53	0.08	208.99
ψ (SHRUB1K + HUMN) p(Time + CANCOV + JDate +Cloud)	8	224.37	0.66	0.08	206.74
ψ (SHRUB1K * NATIVE) p(Time+CANCOV+JDate+Cloud)	9	225.22	1.50	0.05	205.15
Vesper Sparrow					
ψ (FOREST1K * PROP) ε (.) p(~Time + CANCOV + JDate)	9	504.20	0.00	0.71	485.22
Western Kingbird					
ψ (FOREST200 + BRDFEED) γ (ELEV) p(JDate + Cloud)	8	486.32	0.00	0.26	469.54
Western Wood-pewee					
ψ (FOREST1K + TRAFFIC) p(Cloud + CANCOV)	6	188.71	0.00	0.34	175.77
ψ (FOREST1K * TRAFFIC) p(Cloud + CANCOV)	7	190.53	1.82	0.14	175.27
Human-adapted	6	133.35	0.70	0.06	120.90
Barn Swallow					
ψ (NATURAL500 + PROP) p(Time + Rain)	6	151.52	0.00	0.08	138.59
ψ (NATURAL500) p(Time + Rain)	5	152.21	0.69	0.06	141.55
ψ (NATURAL500 + NNWATER) p(Time + Rain)	6	152.36	0.83	0.05	139.42
ψ (NATURAL500 * SHAPE) p(Time + Rain)	7	152.79	1.27	0.04	137.54
ψ (AREA + NATURAL500) p(Time + Rain)	6	152.81	1.28	0.04	139.87

ψ (NATURAL500 + NATIVE) p(Time + Rain)	6	152.86	1.33	0.04	139.92
ψ (NATURAL500 * PROP) p(Time + Rain)	7	152.91	1.39	0.04	137.65
ψ (NATURAL500 + NORTH) p(Time + Rain)	6	152.96	1.43	0.04	140.02
ψ (NATURAL500 * COW) p(Time + Rain)	7	153.18	1.66	0.04	137.92
ψ (NATURAL500 + COW) p(Time + Rain)	6	153.27	1.74	0.03	140.33
Bullock's Oriole					
ψ (DENS3K + GRASS2K) ε (ELEV) p(JDate)	7	352.30	0.00	0.23	337.70
ψ (DENS3K + NORTH) ε (ELEV) p(JDate)	7	354.02	1.72	0.10	339.42
Cliff Swallow					
ψ (AREA + NATURAL3K) ε (.) p(CANCOV)	6	132.64	0.00	0.08	120.19
ψ (NATURAL3K + PROP) ε (.) p(CANCOV)	6	133.19	0.54	0.06	120.74
ψ (NATURAL3K + MOW) ε (.) p(CANCOV)	6	133.35	0.70	0.06	120.90
ψ (NATURAL3K + SHAPE) ε (.) p(CANCOV)	6	133.42	0.78	0.06	120.98
ψ (NATURAL3K + TRAFFIC) ε (.) p(CANCOV)	6	133.96	1.32	0.04	121.51
ψ (NATURAL3K) ε (.) p(CANCOV)	5	134.09	1.44	0.04	123.77
ψ (AREA + DENS3K) ε (.) p(CANCOV)	6	134.33	1.69	0.04	121.88
ψ (NATURAL3K * PROP) ε (.) p(CANCOV)	7	134.37	1.73	0.04	119.77
ψ (NATURAL3K + NNWATER) ε (.) p(CANCOV)	6	134.50	1.86	0.03	122.05
Common Yellowthroat					
ψ (PROP + MOW) p(JDate + Cloud + CANCOV)	7	124.15	0.00	0.14	108.89
ψ (NATIVE * NORTH) p(JDate + Cloud + CANCOV)	8	124.68	0.53	0.11	107.04
ψ (MOW + NORTH) p(JDate + Cloud + CANCOV)	7	124.87	0.72	0.10	109.61
ψ (NATIVE + NORTH) p(JDate + Cloud + CANCOV)	7	125.43	1.28	0.07	110.17
ψ (PROP * MOW) p(JDate + Cloud + CANCOV)	8	125.49	1.34	0.07	107.85
ψ (MOW * NORTH) p(JDate + Cloud + CANCOV)	8	125.75	1.60	0.06	108.11
ψ (AREA * NATIVE) p(JDate + Cloud + CANCOV)	8	125.95	1.80	0.06	108.32
Eastern Kingbird					
ψ (SHRUB3K + PROP) p(Time + JDate)	6	154.02	0.00	0.24	141.08
ψ (SHRUB3K * PROP) p(Time + JDate)	7	154.74	0.73	0.17	139.49
European Starling					
ψ (SHRUB1K + NORTH) p(Time + Wind)	6	164.51	0.00	0.13	151.58
ψ (DENS500 + SHRUB1K) p(Time + Wind)	6	164.75	0.24	0.11	151.81
ψ (SHRUB1K + TRAFFIC) p(Time + Wind)	6	164.88	0.37	0.11	151.94
ψ (DENS500 * SHRUB1K) p(Time + Wind)	7	166.10	1.59	0.06	150.84
House Wren					
ψ (DENS200 + FOREST1K) ε (.) p(Rain + CANCOV)	7	232.23	0.00	0.46	217.63
ψ (DENS200 * FOREST1K) ε (.) p(Rain + CANCOV)	8	233.63	1.40	0.23	216.85

Appendix 4. Top model set (ΔQAICc≤2) of occupancy model selection results for habitat use by a subset of mammal species detected in the CD sites. The number of parameters in the models (*K*), the model weights (*w*), and the deviance (Dev.) are also shown. When the dynamic parameters (γ or ε) are not given in the model name, the parameters have been set equal to zero.

Model	K	QAICc	ΔQAICc	W	Dev
Human-sensitive					
Coyote					
ψ (AREA + DENS200) p(.)	4	599.48	0.00	0.18	590.68
ψ (AREA * DENS200) p(.)	5	600.62	1.13	0.10	589.39
ψ (FOREST3K + PROP) p(.)	4	601.22	1.74	0.07	592.42
Elk					
ψ (SHRUB1K + DENS500) p(JDate)	5	130.91	0.00	0.23	119.69
ψ (SHRUB1K * DENS500) p(JDate)	6	132.25	1.34	0.12	118.50
ψ (SHRUB1K + PROP) p(JDate)	5	132.41	1.49	0.11	121.18
ψ (SHRUB1K * NORTH) p(JDate)	6	132.72	1.81	0.09	118.97
Human-adapted					
Black-tailed Prairie Dog					
ψ (FOREST1K) ε (HRDENS§) p(JDate)	6	152.62	0.00	0.11	140.09
ψ (FOREST1K + TRASH) ε (HRDENS§) p(JDate)	7	152.92	0.30	0.10	138.21
ψ (FOREST1K + DOG) ε (HRDENS§) p(JDate)	7	153.27	0.65	0.08	138.56
ψ (AREA + FOREST1K) ε (HRDENS§) p(JDate)	7	153.36	0.75	0.08	138.65
ψ (FOREST1K + DENS500) ε (HRDENS§) p(JDate)	7	153.99	1.37	0.06	139.28
ψ (FOREST1K + COW) ε (HRDENS§) p(JDate)	7	154.43	1.81	0.04	139.72
ψ (FOREST1K * DOG) ε (HRDENS§) p(JDate)	8	154.62	2.00	0.04	137.69
Cottontail sp.					
ψ (AREA + PROP) ε (ELEV) p(JDate + CANCOV)	8	387.13	0.00	0.04	370.21
ψ (HRDENS§ + PROP) ε (ELEV) p(JDate + CANCOV)	8	387.43	0.29	0.04	370.51
ψ (AG3K) ε (ELEV)p(JDate + CANCOV)	7	387.66	0.52	0.03	372.94
ψ (HRDENS§ * PROP) ε (ELEV) p(JDate + CANCOV)	9	387.89	0.76	0.03	368.73
ψ (AG3K + HRDENS§) ε (ELEV) p(JDate + CANCOV)	8	388.01	0.87	0.03	371.08
ψ (AG3K + PROP) ε (ELEV) p(JDate + CANCOV)	8	388.12	0.98	0.03	371.20
ψ (HRDENS§) ε (ELEV) p(JDate + CANCOV)	7	388.31	1.17	0.02	373.59
ψ (PROP) ε (ELEV) p(JDate + CANCOV)	7	388.32	1.19	0.02	373.61
ψ (AREA * AG3K) ε (ELEV) p(JDate + CANCOV)	9	388.65	1.52	0.02	369.49
ψ (.) ε (ELEV) p(JDate + CANCOV)	6	388.74	1.61	0.02	376.21
ψ (PROP + NNWATER) ε (ELEV) p(JDate + CANCOV)	8	388.86	1.73	0.02	371.94
ψ (HRDENS§ * NNWATER) ε (ELEV) p(JDate + CANCOV)	9	389.10	1.97	0.02	369.94
Mule Deer					
ψ (SHRUB1K) γ (NATURAL) p(CANCOV)	6	400.35	0.00	0.13	387.82
ψ (SHRUB1K + TRAFFIC) γ (NATURAL) p(CANCOV)	7	401.21	0.86	0.08	386.50
ψ (SHRUB1K + PROP) γ (NATURAL) p(CANCOV)	7	401.24	0.89	0.08	386.53
ψ (SHRUB1K + CANCOV) γ (NATURAL) p(CANCOV)	7	401.85	1.50	0.06	387.14
ψ (AREA + SHRUB1K) γ (NATURAL) p(CANCOV)	7	402.15	1.80	0.05	387.44
ψ (SHRUB1K + DOG) γ (NATURAL) p(CANCOV)	7	402.20	1.84	0.05	387.48

ψ (SHRUB1K + DENS1K) γ (NATURAL) p(CANCOV)	7	402.27	1.91	0.05	387.55
ψ (SHRUB1K * TRAFFIC) γ (NATURAL) p(CANCOV)	8	402.28	1.92	0.05	385.36
ψ (SHRUB1K + NORTH) γ (NATURAL) p(CANCOV)	7	402.29	1.94	0.05	387.58
ψ (SHRUB1K + COW) γ (NATURAL) p(CANCOV)	7	402.34	1.98	0.05	387.62
Raccoon					
ψ (SHRUB2K + DENS3K) γ (~HRDENS§) p(.)	6	187.66	0.00	0.09	175.13
ψ (DENS3K) γ (~HRDENS§) p(.)	5	188.86	1.20	0.05	178.48
ψ (SHRUB2K + LIGHT) γ (~HRDENS§) p(.)	6	189.06	1.40	0.05	176.53
ψ (AREA + DENS3K) γ (~HRDENS§) p(.)	6	189.55	1.89	0.04	177.02

§HR indicates that the covariate was scaled to the species average home range size

CHAPTER TWO

CONSULTANTS, SURVEYORS, AND ENGINEERS PLAY A DISPROPORTIONATE ROLE IN IMPLEMENTING CONSERVATION DEVELOPMENT IN COLORADO COUNTIES

INTRODUCTION

It is essential that conservation scientists and practitioners develop and effectively implement a portfolio of conservation strategies to combat accelerated rates of global biodiversity loss (Schipper et al. 2008; Arlettaz et al. 2010; Butchart et al. 2010). Achieving effective conservation is especially important on private lands, which are disproportionately affected by land conversion and human disturbances, and harbor a large proportion of the world's biodiversity (Knight 1999; Miller & Hobbs 2002). Private lands comprise a majority of land area around the world, including approximately 60%, or 5.9 million km^2, of the United States (National Wilderness Institute & U.S. Bureau of the Census 1995), and decreased funding and support for public land acquisition and government regulation means that a majority of conservation efforts will need to be implemented voluntarily by individual citizens and private organizations. Even when County, State, or Federal entities create conservation policy for private lands, individuals or local groups often need to initiate and manage these projects over the long-term (Pierce et al. 2005).

A large body of research has identified social factors as primary determinants of whether conservation actions succeed or fail (Chornesky et al. 2001; Mascia et al. 2003; Hazzah et al. 2009; Knight et al. 2010). Thus, there is an increasing emphasis on the importance of engaging a diverse group of stakeholders in conservation, especially on private lands (Cowling & Wilhelm-

Rechmann 2007; Pressey & Bottrill 2009; Vance-Borland & Holley 2011). The pattern of relationships between people and institutions can impact a group's ability to solve conservation-related problems (Whitten et al. 2001; Ehrlich 2003) and reach desirable compromises between stakeholders (Githiru & Lens 2006). Certain relationship patterns can also increase a group's ability to act in the face of changing conditions (Bodin et al. 2006), and influence the overall success of sustainable resource management and preservation of ecosystem services (Burgess et al. 2009). Within groups of stakeholders, individual actors can often serve pivotal roles. For example, highly connected or influential individuals can facilitate social learning among groups (Schusler & Decker 2003; Prell et al. 2008), encourage support for conservation actions (Olsson et al. 2004; Crona & Bodin 2006; Reed et al. 2009), provide connections for collaboration among other individuals (Rathwell & Peterson 2012), and influence the behaviors of stakeholders in a system (Rogers 1995; Prell et al. 2008; Reed et al. 2009).

Social Network Analysis (SNA) is an analytical method founded in graph theory that examines the relationships (i.e. ties) between a set of actors (i.e. vertices) within a defined network (Wasserman & Faust 1994). Although SNA dates back to the 1930's (Moreno 1934), it has only recently been utilized to explore questions about how connections between stakeholders influence natural resource management and conservation actions (e.g., Tompkins & Adger 2004; Newman & Dale 2005; Bodin et al. 2006; Vance-Borland & Holley 2011). SNA quantitatively measures the characteristics of the connections between a set of actors within a clearly defined area (Bodin et al. 2006). It provides information about patterns in actor relationships across the entire network as well as metrics that specifically quantify the position and contribution of individual actors within the network (Wasserman & Faust 1994). This information could be especially valuable in gaining a better understand of participation in voluntary conservation projects on private lands (Vance-Borland & Holley 2011). Furthermore, identifying the most influential actors could help biological scientists to better target recommendations to improve their conservation effectiveness.

In this study, I used SNA to examine participation in the implementation of a widespread and emerging private land conservation strategy called Conservation Development (CD). Especially on private lands, residential sprawl and commercial development are among the leading threats to biodiversity and ecosystem services (Brooks et al. 2002; Schipper et al. 2008). CD refers to a range of development strategies that seek to minimize the impacts of residential or commercial land uses on natural resources (Pejchar et al. 2007; Milder & Clark 2011). CD has been widely implemented, and now represents approximately one-fourth of private lands conserved in the United States (Milder & Clark 2011). For this study, I specifically examined CD subdivisions, which cluster houses in a small portion of a property while preserving the remaining land as protected open space (Pejchar et al. 2007; Milder 2007). These subdivisions are an alternative to exurban development, or low-density residential sprawl located outside of incorporated cities and towns (Pejchar et al. 2007; Milder 2007). The practice of CD was popularized in the 1990's, and it could potentially offer a number of social, economic, and ecological benefits (Arendt 1996), including resident access to recreation and open space (Pejchar et al. 2007; Milder & Clark 2011), greater home and land values (Hannum et al. 2012), reduced soil erosion and stormwater runoff (Arendt 1996), and the preservation of wildlife habitat and ecosystem services (Odell et al. 2003; Hansen et al. 2005).

In theory, CD is an economically viable way to preserve private land while balancing housing needs for a growing population. In practice, however, CDs makes up a relatively small proportion of housing developments in the U.S. (McMahon & Pawlukiewicz 2002; Mockrin et al. In Review), and some studies have noted that CDs may not be achieving conservation objectives due to insufficient design and long-term stewardship (Lenth et al. 2006; Hostetler & Drake 2009). The success of a CD subdivision is dictated by the collective actions of the many individuals and organizations involved in the design, construction and stewardship of the development, and understanding the social network of CD participants can provide information to help improve the practice of CD. Examining the pattern of connections between actors that design and develop CD subdivisions can provide information to help explain the uneven rates of implementation of CDs in different areas (Reed et al. 2014). Identifying the important or well-connected stakeholders in CD implementation can also help inform conservation scientists about how and where to communicate recommendations to improve the effectiveness of CD for achieving conservation objectives. For example, if certain types of stakeholders were consistently involved in a number of CD subdivision projects, it would be strategic to engage with these individuals directly to improve CD practice.

To better understand the social patterns and drivers of CD implementation, I used SNA to quantify network characteristics and actor participation in CD subdivisions in six counties in Colorado, USA. My research objectives for this study were to 1) Identify the individuals and organizations that are most consistently associated with the implementation of CDs within each county, and 2) Examine and compare the patterns of actor participation in CDs between counties. By identifying important actors with whom to communicate best practices, the outcomes of this study could improve CD as a strategy for preserving biodiversity and ecosystem services on private lands.

METHODS

Data Collection

I collected information from publicly available records for all existing CDs in six Colorado counties: Boulder, Chaffee, Douglas, Larimer, Mesa, and Routt. These counties were selected because they include a breadth of population sizes, land areas, socio-economic and ecological conditions (Table 1). They contain 302 total CDs, which is the majority (86%) of the 352 CDs documented in the state (Hannum et al. 2012). Boulder County currently has 143 CDs, Chaffee County has 19 CDs, Douglas County has 16 CDs, Larimer County has 89 CDs, Mesa County has 19 CDs, and Routt County has 16 CDs. I read through each CD's county record file and recorded all of the individuals and organizations (henceforth: actors) that were listed as being involved in any stage of design, planning, and construction. I also recorded the role that they performed for each CD (e.g., engineer, biological consultant), and noted whether the actors performed multiple roles in a given CD.

Statistical Analysis

I used social network analysis (SNA) to quantitatively assess the structural patterns of individuals and organizations associated with the implementation of all CD projects within the six selected Colorado counties. Because land-use regulation and incentives for CD are most often implemented at the county level in the western United States (Reed et al. 2014), I investigated each county as its own separate network. I created an adjacency matrix for each county, with all actors for the network along the rows and columns. A value of "1" was entered into the cells of actors that had worked on the same CD project, while cells of those that had not interacted on any projects together were given a "0." The CD subdivisions were approved within 20 years of each other for all but one of the counties investigated. In Larimer County, one CD fell outside this range. Because the likelihood of interaction among actors across CDs decreases as the ages of the subdivisions diverge, I eliminated this CD from the analysis.

Using packages sna (Butts 2010) and igraph (Csardi & Nepusz 2006) in R (RDevelopmentCore Team 2014), I calculated network density and centralization for each county. The density of the network is the proportion of all of the possible ties that are present in the network (Wasserman & Faust 1994), and indicates the degree to which all of the actors are connected to one another. Centralization indicates how unequal the distribution of connections is in the network (Wasserman & Faust 1994). For example, a centralization score of one indicates that the majority of ties are held by only one actor, and a score of zero indicates that all actors are connected to one another (Schneider et al. 2003). I mapped relationships between network actors for each county's network, and I compared values of density and centralization to determine whether patterns of actor participation in CD differ between counties. I also used Pearson's Product Moment Correlation to test for linear relationships between county density and centralization and the county's population, land area, timespan of CD implementation, number of CDs, and total number of actors in the network (Table 1).

I calculated the betweenness centrality and degree centrality for all actors to determine the most important actors and actor classification types within and across the counties. Betweenness centrality indicates the frequency that an actor falls on the paths between pairs of other actors (Freeman 1979), and degree centrality indicates the number of other actors to which the focal actor is tied (Freeman 1979). I first used a Kruskal-Wallis Rank Sum Test and post hoc pairwise Wilcoxon tests to determine whether there were significant differences between the sums of the ranks of actor types for degree centrality and betweenness centrality across all counties. Using the rank sum of actor centrality allowed me to make inference about actor types across the different counties that had a different number of actors per network (Kruskal & Wallis 1952). I then used one-way ANOVA to test whether certain actor types tended to have higher centrality scores within each county. I used Tukey's post hoc tests to determine which actor categories had significantly higher centrality scores. Finally, I classified key actors for each county network as those within the top 25% of all of the degree centrality and betweenness centrality scores for actors in the network.

RESULTS

A total of 719 individuals and organizations were associated with CD implementation in the 6 counties examined (Table 3, Figure 1). Three hundred ninety-four were owners or developers, 101 were surveyors, 94 were engineers, 73 were planners, 39 were biological consultants, 26 were geological consultants, 24 were other consultants (including traffic congestion consultants, irrigation consultants, and percolation consultants), 15 were architects or landscape architects, 13 were soils consultants, 8 were construction companies, 7 were realtors, 3 were ecological assessors, and 2 were cultural/archaeological consultants. In 72 cases, the same actor had multiple roles in implementation. For example, many companies provided both engineering and surveying services.

County Networks

The network densities, or proportion of possible ties that were actually present in the network, differed for each county (Table 1). Routt County's density was 8.9 times greater and Chaffee County's density was 8.3 times greater than Boulder County, which had the lowest network density. The networks for Mesa County and Douglas County each had mid-level density scores, while Larimer County and Boulder County had the least connected networks.

Centralization also differed between counties (Table 1). Chaffee County had the highest centralization of all the networks examined, which indicates that it had the fewest actors holding the greatest number of ties. Chaffee County's centralization was 2.7 times greater than Boulder, the county with the lowest centralization. The networks for Douglas County and Routt County also had high centralization compared to the other counties examined; the centralization scores for each of these counties were 2.4 and 2.1 times greater than Boulder County. Larimer County also had a low centralization, indicating that the connections in Boulder County and Larimer County are split more evenly among actors than connections in the other county networks.

There were strong negative correlations between network density and a county's population (Pearson r= -0.86, $p<0.05$), the total number of CDs in the county (Pearson r= -0.901, $p<0.05$), and the total number of actors in the network (Pearson r= -0.959, $p<0.05$) (Table 2). There was also a strong negative correlation between network centralization and the number of actors in the network (Pearson r= 0.828, $p<0.05$) (Table 2).

Key Actors

Biological and geological consultants, surveyors, engineers, and planners were consistently the most well-connected actors both within and across county networks. There were significant differences among the ranks of actor types by degree centrality ($\chi^2 = 115.0$, $p<0.001$) across all counties. Biological consultants ($p<0.0001$), engineers ($p<0.0001$), geological consultants ($p=0.001$), other consultants ($p<0.05$), planners ($p<0.05$) and surveyors ($p<0.0001$) were ranked significantly higher than owner/developers. Overall, there were also significant differences among the ranks for actor types by betweenness centrality ($\chi^2 = 33.8$, $p<0.05$), but a post-hoc pairwise Wilcoxon test revealed no significant differences between individual actor types.

Degree centrality for different actor types differed significantly in Boulder County ($F=5.702$, $p<0.0001$), Chaffee County ($F=12.72$, $p<0.0001$), Larimer County ($F=4.274$, $p<0.001$), and Routt County ($F=4.274$, $p=0.01$). Geological/soils consultants in Boulder County had degree centrality scores 2.1 times greater than surveyors ($p<0.05$), 2.5 times greater than engineers ($p<0.05$) and planners ($p<0.005$), and 5.3 times greater than owner/developers ($p<0.0001$) (Figure 2). Surveyors in Boulder County had 2.6 times higher degree centrality scores than owner/developers ($p<0.005$) (Figure 2). In Chaffee County, biological consultants had significantly greater degree centrality than other actors, with scores twice as large as geological consultants ($p <0.05$), 2.6 times greater than surveyors ($p<0.005$) and 6.2 times greater than owner/developers ($p<0.0001$). In Larimer County, biological consultants, engineers, and surveyors all had similarly high degree centrality scores, which were 2.5-2.8 times greater than the scores of owner/developers ($p<0.05$) (Figure 2). Planners had the highest degree centrality in Routt County, with scores an average of 2.6 times greater than those of biological consultants ($p<0.05$), and 3.3 times greater than owner/developers ($p<0.05$) (Figure 2).

Betweenness Centrality for different actor types differed significantly in Boulder County ($F= 4.263$ $p<0.0001$), Chaffee County ($F= 7.086$, $p<0.001$), and Larimer County ($F=3.3$, $p<0.001$), and patterns were similar to those of degree centrality scores for most counties. In Boulder County, betweenness centrality scores for geological/soils consultants were 2.9 times greater than surveyors ($p<0.05$), 3.7 times higher than engineers ($p<0.05$), 4.2 times higher than planners ($p<0.005$), and 18.4 times higher than owner/developers ($p<0.0001$). Betweenness centrality scores for biological consultants in Chaffee County were 5.4 times greater than surveyors ($p<0.05$), 13.9 times greater than geological consultants ($p <0.05$), and 201.1 times greater than owner/developers ($p<0.0001$) (Figure 3). In Larimer County, engineers and surveyors each had betweenness centrality scores nine times greater than owner/developers ($p<0.05$) (Figure 3).

The composition of key actors within the top 25% of degree centrality and betweenness centrality scores also shows that the most well-connected actors tended to be surveyors, engineers, or a type of consultant (Table 4). Specifically, 21% of actors with the top 25% of degree centrality scores were geological consultants, 18% of the key actors for degree centrality were surveyors, 15% were biological consultants, and 13% were engineers (Table 4). A majority of actors (77%) with the top 25% of betweenness centrality scores were a type of consultant; 44% were biological consultants, and one-third (33%) were geological consultants (Table 4).

DISCUSSION

CD is a widespread and growing private land conservation strategy (Pejchar et al. 2007; Milder & Clark 2011). In order to ensure that CDs effectively achieve their conservation goals, it is important to understand the social patterns and drivers of their implementation. In this study, I examined the social networks of CDs in six Colorado counties in order to quantify participation by individuals and institutions in multiple CD subdivisions. I found that the network characteristics differed between counties, and ranged from counties with fewer than 2% of the possible actor connections present to those with almost 15% of the possible connections. Networks also differed in the distribution of connections between actors. With centralization scores greater than 0.5, several counties had only a few actors holding the majority of ties. Other counties had a more even distribution of connections among many actors. Both across and within counties, actors that were involved in the implementation of the most CDs were consistently those that worked as biological and geological consultants, surveyors, engineers, and planners. In many cases, actors in these groups had two to three times greater degree centrality and betweenness centrality scores than other actor types.

County Network Characteristics

Routt County was the most highly connected network that I examined, and it had approximately nine times the density, or proportion of possible actor connections present, than Boulder County, the least connected network. Overall, there were strong negative correlations between network densities and the population of the county, the total number of CDs in the county, and the total number of actors in the network. Boulder County and Larimer County, for example, had the lowest densities, the highest populations, and the highest number of CDs of all the counties. It is possible that these counties may have a low proportion of connections because the large number of actors available to participate in the implementation of any given CD decreases the likelihood that actors will consistently be able to work together on multiple CDs. A higher density of connections within a network may encourage the spread of information and increase accessibility to information by a diversity of stakeholders (Weimann 1982; Abrahamson & Rosenkopf 1997). These types of ties among actors can encourage mutual learning and sharing advice (Crona & Bodin 2006; Newman & Dale 2004, 2007), actions that could help improve the overall practice and implementation of CD. Further research might examine how the density of a county network influences how effectively CDs achieve successful conservation outcomes.

The networks for Douglas County and Chaffee County had the highest centralization, and in both cases the two most well-connected actors held 1.5-4 times the number of ties of any other actor in the network. Boulder County, Larimer County, and Mesa County had centralization scores that were half as large as Douglas County and Chaffee County. The connections in these counties were much more evenly distributed across a number of actors. Networks with high centralization can be extremely efficient for spreading information consistently, as long as the highly centralized actors receive and relay the information through their connections (Leavitt 1951; Crona & Bodin 2006; Olsson et al. 2004). However, some research suggests that less centralized networks will be more beneficial for long-term management of shared resources because a larger and more diverse group of stakeholders can share connections and information (Crona & Bodin, 2006). Future research might examine how information about best practices for CD design and stewardship is communicated through different types of networks.

Scientists often have limited time and support for implementation and outreach to achieve conservation action (Arlettaz et al. 2010), so it is essential to make the process as efficient and effective as possible. Understanding the network characteristics of CD stakeholders could inform how conservation scientists shape their outreach strategies. For example, in counties that have a lower network density and relatively few connections between stakeholders, conservation scientists could use broad information dissemination techniques such as public meetings in order to distribute information about best practices for CD. In counties with high centralization, conservation scientists could identify the highly connected actors and contact those individuals directly in order to exchange information and recommendations. Social network analysis should be used in other locations to assess the community of individuals participating in CD and other conservation strategies; it could help ensure that scientists are able to target their effort and reach the most important stakeholders (Prell et al. 2009; Vance-Borland & Holley 2011).

Key Actors

Across all counties, biological, geological, and other consultants had significantly higher degree centrality scores than other types of actors, and their scores were disproportionately high compared with their overall representation in the networks. Many of the highly connected actor types within different counties also tended to be biological and geological consultants, and some counties also had surveyors, planners, and engineers included among their highest connected actor types. In order to successfully contribute their expertise to improving CD effectiveness, conservation scientists need to engage with the practitioners that often implement these projects (Arlettaz et al. 2010; Pressey & Bottrill 2009). The typical strategy to improve CDs is for scientists to engage in land-use policy decisions and target their outreach to the planning offices of local municipalities (Theobald et al. 2005; Berke 2007; Miller et al. 2008; Broberg 2003; Reed et al. 2014). However, my findings indicate that there are other individuals and organizations that frequently participate in CD implementation; conservation scientists should consider targeting these stakeholders for collaboration and outreach efforts. Local planners and other practitioners can also use this information to develop targeted ordinances or certification programs for especially important groups.

In many counties, actor types with the highest betweenness centrality scores were those that worked on CD subdivisions as geological and biological consultants, engineers, and surveyors. Betweenness centrality measures the degree to which individual actors link otherwise disconnected actors, so these actors could be especially important for spreading information between groups of individuals associated with CD implementation. Often, actors with high betweenness centrality are referred to as "brokers," and provide bridging links throughout the community (Burt 2003; Newman & Dale 2005). It is important to note that some of the well-connected players in the networks I examined may not hold the power to dictate the way the CDs are designed, constructed, and managed. However, even when "brokers" lack decision-making power, they could still be extremely important if they spread ideas and information about how to effectively build and manage CDs to the actors in charge of important design and stewardship decisions.

Several authors have noted the importance of conducting an ecological assessment to design CD subdivisions that effectively preserve the ecologically important areas of a parcel of land (Arendt 1996; Pejchar et al. 2007; Hostetler & Drake 2009). However, CD ordinances rarely require that this type of assessment take place prior to designing a CD subdivision, and even fewer require consultation with a biological expert in CD site assessment and design (Reed et al. 2014). Our analysis demonstrates that biological consultants are consistently involved in CD implementation, but rarely conduct pre-design assessments. CD ordinances should require an ecological assessment as part of the process of designing and implementing a CD subdivision (Reed et al. 2014). As an actor type that tends to work on multiple CD projects, biological consultants are well-positioned to conduct these pre-design assessments and provide suggestions for effective CD design that preserves high-quality habitat for wildlife conservation. Best practices should also be developed for biological consultants working on CDs to ensure that they contribute beneficial data and guidance to CD projects. Finally, third-party certification programs could provide oversight and ensure that consultants have up to date scientific information regarding CD design and stewardship, similar to the role of the Rainforest Alliance or the Forest Stewardship Council in sustainable farming practices.

Surveyors, engineers, and private planning companies were also important actor types in the county networks, and members of these groups often had direct connections or bridging links with many other stakeholders involved in CD implementation. Individuals and organizations from these groups are less likely to have a background in biology or conservation science, but often make important decisions regarding CD site design (Beatley 2007; Hostetler & Drake

2009). CD ordinances should require that these actors contract externally or work as part of a team with scientists or environmental consultants as they design the CD (Brush 1976; Longrie 1976). Specific trainings and best practices programs could also provide specific information and recommendations to these groups about how to design CDs to maximize their contribution to conservation objectives. Conservation scientists could also develop CD certification or education programs in partnership with professional organizations for these groups, such as the National Society of Professional Surveyors and the American Planning Association.

A "research-implementation gap" has been observed in a growing body of research regarding many conservation strategies (Pfeffer & Sutton 1999; Opdam et al. 2002; Arlettaz et al. 2010), and it is possible that CD also suffers from a disconnect between research and the successful implementation of conservation action. In some cases, the research-implementation gap can result from a lack of effective communication between scientists and practitioners (Brush 1976; Pullin et al., 2004; Sutherland et al. 2011). In others, economic and social constraints decrease the likelihood of effective implementation (Knight et al. 2008; Arlettaz et al. 2010). It has also been hypothesized that, because scientific research is rarely designed in collaboration with practitioners, scientific recommendations do not reflect practical concerns related to implementation (Knight et al. 2008). Identifying the important individuals and organizations associated with CD implementation can help bridge the research-implementation gap and inform effective collaboration between many types of practitioners, scientists, and stakeholders.

Conclusion

CD is a widespread private land conservation strategy with social, economic, and environmental benefits, and it could be a valuable tool used to combat global biodiversity loss in urbanizing areas. As research scientists generate relevant information about effective design, construction, and stewardship strategies for CD, it is important to communicate those findings to the individuals and organizations involved in its implementation. However, the networks of stakeholders involved with the conservation of private lands can be as complex and diverse as the ecological systems they are trying to preserve. This study demonstrates that social network analysis can provide information about network and actor characteristics that can inform outreach and communication efforts. This approach could be used to help CD achieve its potential as one of many conservation strategies used to preserve biodiversity on private lands in an increasingly urbanized world.

TABLES

Table 1. Density and centralization of the social networks of actor participation in the implementation of CD subdivisions in six Colorado counties, and characteristics of each county.

County	Network Density	Network Centralization	Population	Land Area (km^2)	Implementation Time-span (years)	# of CDs	# of Actors
Routt	0.143	0.441	23,513	6,133	13	16	37
Chaffee	0.133	0.573	18,510	2,629	7	19	35
Mesa	0.097	0.290	147,554	8,653	8	19	63
Douglas	0.096	0.524	305,963	2,183	14	16	48
Larimer	0.023	0.226	315,988	6,822	19	89	254
Boulder	0.016	0.211	310,048	1,945	19	143	279

Table 2. Pearson correlations between county network characteristics, density and centralization, and a number of county characteristics. The significant correlations ($p<0.05$) are presented in bold.

County characteristic	Pearson correlation (r)	p-value
Network Density		
County population	**-0.860**	**0.028**
County land area	0.081	0.879
CD implementation time-span	-0.806	0.053
Number of CDs	**-0.901**	**0.014**
Number of Actors in the network	**-0.959**	**0.003**
Network Centralization		
County population	-0.558	0.250
County land area	-0.401	0.430
CD implementation time-span	-0.619	0.190
Number of CDs	-0.760	0.079
Number of Actors in the network	**-0.828**	**0.042**

Table 3. The number and percentage of actors that served as each actor classification type for CD implementation in six Colorado Counties.

Actor Type	Boulder County	Chaffee County	Douglas County	Larimer County	Mesa County	Routt County
Architect	0 (0%)	0 (0%)	0 (0%)	4 (1.4%)	0 (0%)	1 (2.5%)
Archeological Consultant	0 (0%)	0 (0%)	2 (4.2%)	0 (0%)	0 (0%)	0 (0%)
Biological Consultant	4 (1.2%)	2 (5.6%)	5 (10.4%)	17 (6%)	4 (5.8%)	7 (17.5%)
Construction Company	0 (0%)	0 (0%)	0 (0%)	4 (1.4%)	4 (5.8%)	0 (0%)
Ecological Assessment	0 (0%)	0 (0%)	1 (2.1%)	2 (0.7%)	0 (0%)	0 (0%)
Engineer	38 (11.6%)	1 (2.8%)	5 (10.4%)	35 (12.4%)	12 (17.4%)	5 (12.5%)
Geological/Soils Consultant	13 (4%)	4 (11.1%)	2 (4.2%)	7 (2.5%)	10 (14.5%)	3 (7.5%)
Landscape Architect	1 (0.3%)	0 (0%)	2 (4.2%)	6 (2.1%)	0 (0%)	1 (2.5%)
Other Consultant	9 (2.8%)	0 (0%)	0 (0%)	14 (4.9%)	1 (1.4%)	0 (0%)
Owner/Developer	161 (49.2%)	22 (61.1%)	24 (50%)	148 (52.3%)	27 (39.1%)	14 (35%)
Planner	46 (14.1%)	0 (0%)	1 (2.1%)	19 (6.7%)	2 (2.9%)	5 (12.5%)
Realtor	3 (0.9%)	0 (0%)	0 (0%)	2 (0.7%)	1 (1.4%)	1 (2.5%)
Surveyor	52 (15.9%)	7 (19.4%)	6 (12.5%)	25 (8.8%)	8 (11.6%)	3 (7.5%)

Table 4. Actors in the top 25% of degree centrality and betweenness centrality scores for each Colorado county examined. Actor categories indicate the way that the actor participated in CD implementation.

Actor Code	Actor Category	Degree Centrality	Betweenness Centrality
Boulder County			
B4	Surveyor/Planner/Engineer	63*	9942.8*
B6	Geological Consultant	57*	12351.7*
B56	Geological Consultant	40*	5056.0
B32	Surveyor	38*	6736.3
B16	Soil Consultant	34*	3668.7
B20	Surveyor	20*	3041.4
B24	Geological Consultant	19*	2215.3
B13	Surveyor/Planner/Engineer	13*	1212.9
B12	Surveyor	12*	1963.2
Chaffee County			
C11	Biological Consultant	24*	388.7*
C19	Engineer/Surveyor	11*	160.5
Douglas County			
D23	Biological Consultant	30*	538*
D13	Surveyor	11*	202
D14	Surveyor	11*	12
Larimer County			
L31	Surveyor/Engineer	63*	8737.8*
L37	Biological Consultant	54*	9457.7*
L18	Surveyor/Engineer	35*	4436.3
L9	Surveyor/Engineer	34*	5643.7
L14	Engineer	29*	2481.5
L12	Geological Consultant	25*	3428.3
L30	Engineer	21*	406.0
L22	Surveyor/Engineer	19*	3428.3
L16	Engineer	18*	2479.2
L23	Biological Consultant	16*	2005.9
L25	Engineer	16*	789.6
L13	Other Consultant	15*	1383.7
L17	Other Consultant	14*	1126.1
L4	Biological Consultant	14*	741.1
Mesa County			
M23	Geological Consultant	24*	614.4*
M32	Geological Consultant	18*	436.1*
M5	Surveyor	15*	275.6
M33	Construction Company	11*	168.8
M8	Engineer	10*	186.5
M13	Geological Consultant	10*	114.9
M20	Geological Consultant	9*	211.8
M12	Engineer/Surveyor	9*	179.1
Routt			
R5	Biological Consultant	21*	267.2*
R23	Surveyor	15*	116.7
R16	Surveyor/Planner/Engineer	13*	68.3

*The actor is a "key actor" and is in the top 25% of the degree centrality or betweenness centrality for the network

FIGURES

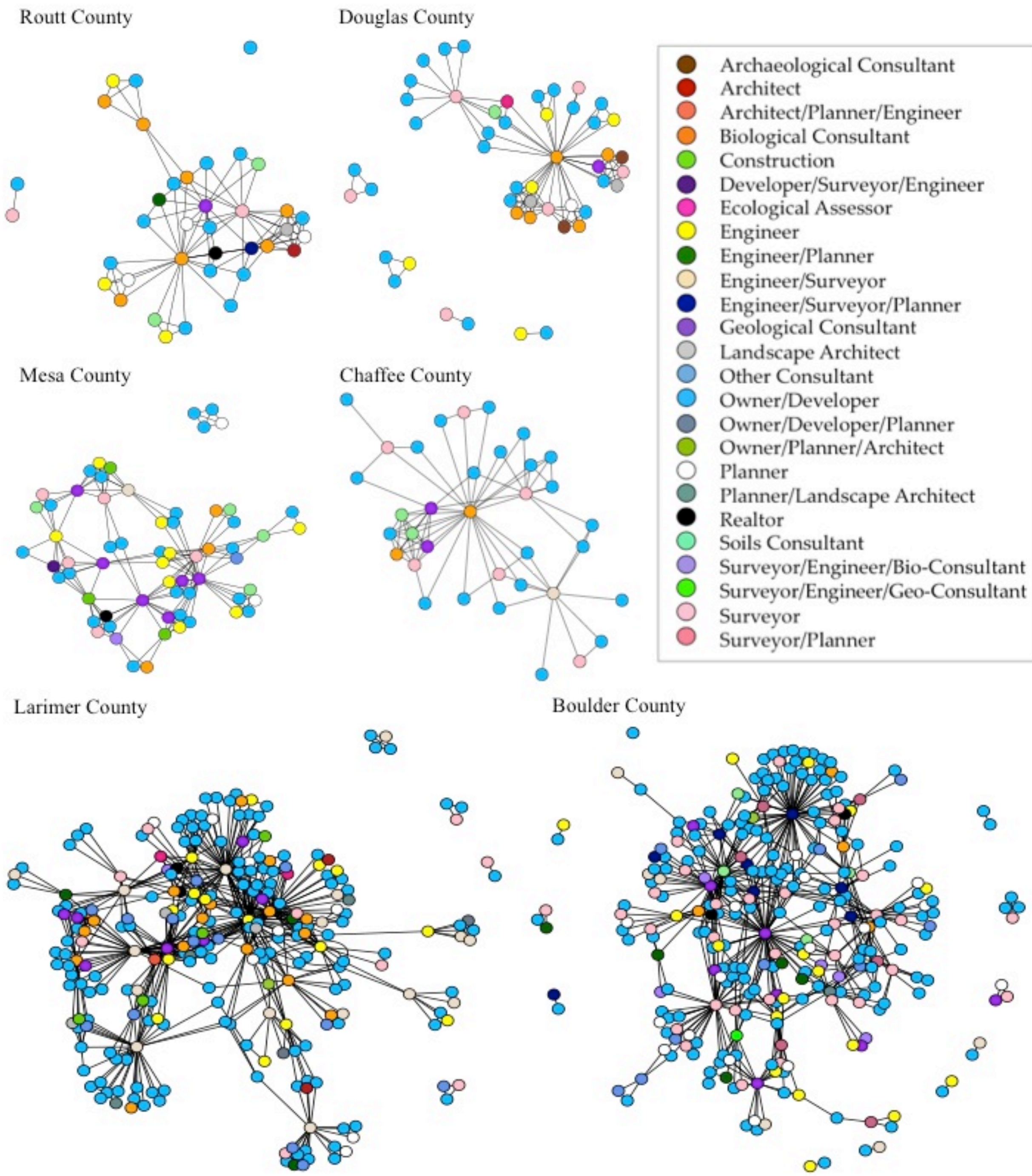

Fig. 1. Social Networks for six Colorado counties: Routt, Douglas, Mesa, Chaffee, Larimer, and Boulder. Actors are indicated with a circle, actor type by color, and connections between actors are shown with a line.

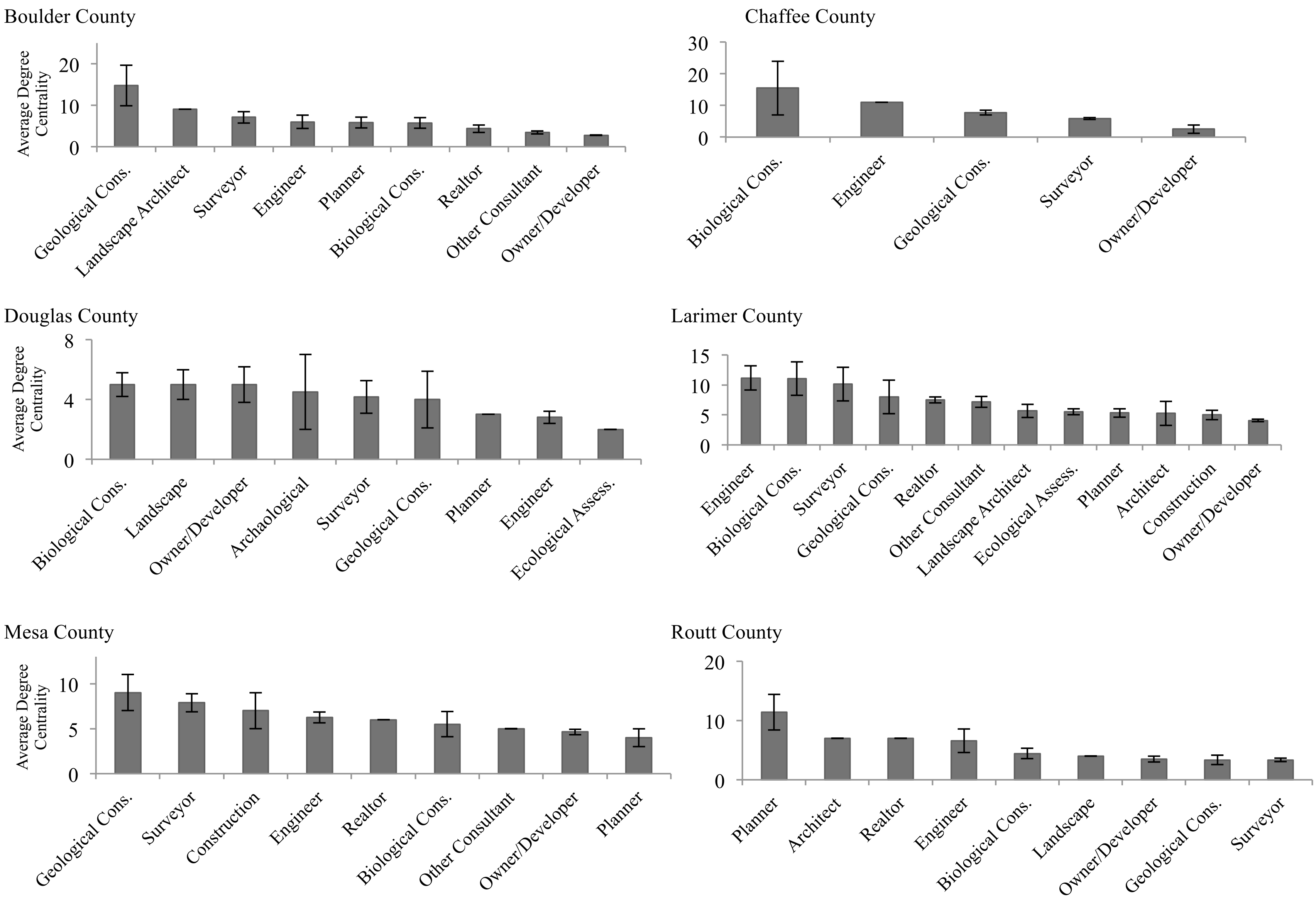

Fig. 2. Mean degree centrality scores for each of the actor category types for actors that participated in the implementation of CD subdivisions in Boulder County, Chaffee County, Douglas County, Larimer County, Mesa County, and Routt County, Colorado.

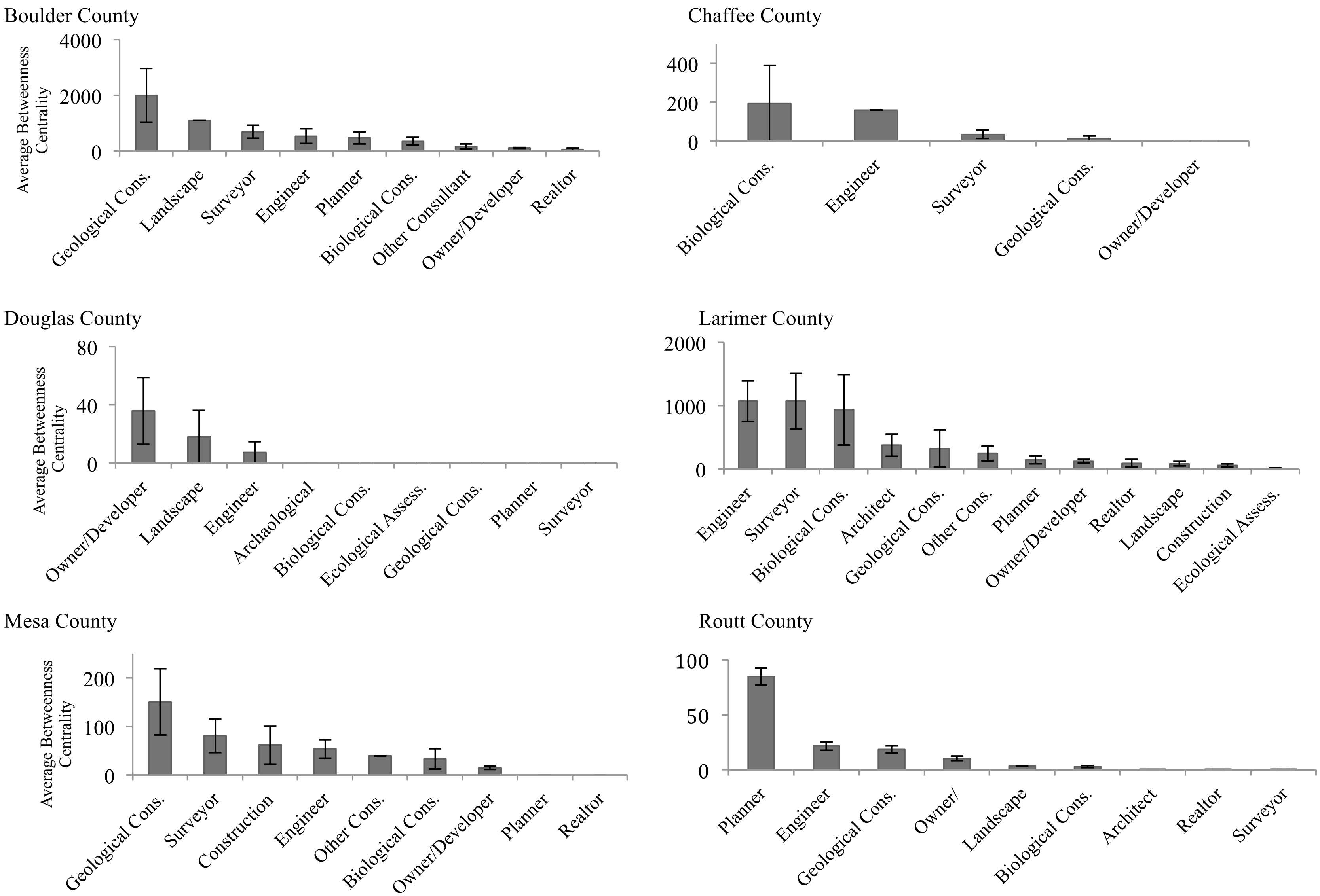

Fig. 3. Mean betweenness centrality scores for each of the actor category types for actors that participated in the implementation of CD subdivisions in Boulder County, Chaffee County, Douglas County, Larimer County, Mesa County, and Routt County, Colorado.

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CHAPTER THREE

CONSERVATION DEVELOPMENT MANAGEMENT DOCUMENTS RARELY ADDRESS BIOLOGICAL PROTECTION OBJECTIVES

INTRODUCTION

Private lands offer a unique opportunity for conservation; over 60% of the U.S. is privately owned and nearly all threatened species occur on private land (Knight 1999). However, expanding housing needs have resulted in the conversion of many private forests, grasslands, farms and ranchlands to exurban residential development (Hansen et al. 2005), and developing effective tools for conservation on private lands is becoming increasingly important for global biodiversity conservation (Schipper et al. 2008; Butchart et al. 2010). Conservation development (CD) is a widely implemented private land conservation strategy that has potential to contribute substantially to the protection of private lands in countries around the world (Langholz & Lassoie 2001; Corcuera et al. 2002; Pejchar et al. 2007). CD is an alternative to residential sprawl designed to decrease negative environmental impacts by clustering houses in a small portion of a property while preserving the remaining land as protected open space (Pejchar et al. 2007; Milder 2007). CD has been in use for over four decades and occupies four million hectares of land in the United States, accounting for approximately one-fourth of private lands conservation (Milder & Clark 2011). However, the overall contribution of CDs to private land conservation is poorly understood, and little research has assessed the degree to which CDs protect healthy and diverse wildlife communities over time (Lenth et al. 2006; Hostetler & Drake 2009).

In the western U.S., CD is often regulated via ordinances adopted by county planning agencies (Reed et al. 2014). County governments can encourage CD by employing long-term vision documents such as comprehensive plans or regulations such as subdivision and zoning ordinances (Jurgensmeyer & Roberts 1998; Ellickson & Been 2000; Pejchar et al. 2007). They might also provide incentives to create CDs, such as density bonuses or expedited review of development proposals (Pejchar et al. 2007; Reed et al. 2014). Currently, over 30% of counties in the western United States have ordinances regulating CD (Reed et al. 2014).

Recent studies have pointed out the necessity of management plans and funding to support long-term open space stewardship in CDs (Pejchar et al. 2007; Hostetler & Drake, 2009; Hostetler et al. 2011; Hostetler 2012; Reed et al., 2014). However, current guidelines for CD tend to focus on the design phase and neglect long-term stewardship of the protected land (Hostetler 2012; Hostetler & Drake 2009). For example, almost three fourths of CD ordinances in the western U.S. do not require a plan for protected land management (Reed et al. 2014). When management plans are created, they often lack long-term funding (Romero & Hostetler 2007). Even when homeowners are willing to pay for conservation features, developers are often opposed to using mechanisms such as HOA dues and property taxes to generate funding for stewardship (Feinberg et al. 2015).

Long-term stewardship and effective management practices are critical for successful species conservation in protected areas (Hockings 2003; Hockings et al. 2004; Chape et al. 2005). Assessing and improving management practices is especially important on private lands and in residential areas, because homeowner behaviors can significantly impact local plant and animal communities (Lerman et al. 2012). For example, common practices in residential areas such as pruning shrubs and removing snags can decrease habitat for arthropods and cavity nesting birds (Mannan et al. 1980; Faeth et al. 2011). Fertilizers and pesticides used on residential lawns can deposit excessive nutrients and toxins into local streams and water bodies (Hostetler & Drake 2009), and plant communities altered by landscaping and gardening vegetation can also impact local biodiversity (Chamberlain et al. 2004; Lerman & Warren 2011). Human behaviors in protected areas can cause significant disturbance to animals; recreation can increase wildlife flight and vigilance activities (Mainini et al. 1993; George & Crooks 2006; Ordeñana et al. 2009), and high levels of anthropogenic noise or light will decrease occurrence by certain species (Miller 2006; Barber et al. 2010). Predation by domestic cats can also be extremely detrimental to local bird and small mammal populations (Baker et al. 2008), and homeowner behaviors dictate whether cats are allowed to roam outdoors.

In residential areas, aesthetic goals for human communities and priorities for conservation are often at odds (Borgstrom et al. 2006; Ernston et al. 2010). CD is a conservation strategy that balances housing and conservation objectives, so providing guidance on best practices for short- and long-term stewardship is critical to ensure that both objectives are met. Many CD residents are unaware of the ways human activities diminish biodiversity, and they lack knowledge of effective strategies for open space management and environmentally sound land use (Youngentob & Hostetler 2005). Without sufficient direction for stewardship, residents could fail to act or engage in harmful practices in ways that undermine the CD's conservation objectives. Several papers and books have used evidence from ecological literature to provide suggestions to improve CD management for wildlife habitat conservation (Pejchar et al. 2007; Milder 2007; Hostetler & Drake 2009; Hostetler 2012). However, little is currently known about whether developers and landowners follow best practices to create and manage CD subdivisions that achieve conservation objectives.

In this study, I formally assessed the content of conservation easements and management plans for existing CD subdivisions in six Colorado counties. The content of these documents can provide valuable information about the land uses and activities that occur in the open space of existing CDs. My research questions were: 1) What proportion of CDs have management/ stewardship documents?, 2) Which stewardship activities and land use practices do these documents prohibit, permit, encourage, or require?, and 3) Which of these activities and practices are most and least frequently addressed in these documents? By evaluating current guidelines for management, this research can help prioritize strategies to improve CD as an effective tool for conservation on private lands.

METHODS

Data Collection

I collected information from publicly available records for all existing CDs in six Colorado counties: Boulder, Chaffee, Douglas, Larimer, Mesa, and Routt. These counties contain 302 total CDs, which is the majority (86%) of the 352 CDs in the state. Boulder County currently has 143 CDs, Chaffee County has 19 CDs, Douglas County has 16 CDs, Larimer County has 89 CDs, Mesa County has 19 CDs, and Routt County has 16 CDs. For each CD, I recorded whether the CD had a document or plan on file that provided guidelines or regulations regarding stewardship of CD open space. I define stewardship to include land uses and human activities, ecological restoration, revegetation, education initiatives, and management practices. The documents on file were often conservation easements or management plans, and they either prohibited, permitted, encouraged, or required various activities and land uses in the protected open space.

I used a set of detailed criteria to review the content of each management document (Ordonez & Duinker 2013; Reed et al. 2014) (Appendix 1). I first noted whether the management documents stated the reason for preserving the open space. I then developed a list of stewardship activities and land uses that I expected to find in the management documents by referencing relevant literature that recommends guidelines for CD stewardship (Arendt 1996; Lenth et al. 2006; Pejchar et al. 2007; Milder 2007; Hostetler & Drake 2009; Hostetler 2012), and other literature regarding the content of land management plans (Rissman et al. 2007; Wilhere 2002; Ordonez & Duinker 2013) (Appendix 1). As I reviewed management documents, I added stewardship activities and land uses that appeared in the documents but were not included in my original list. For each stewardship activity and land use mentioned, I recorded whether the item was prohibited, permitted, encouraged, or required.

I collected information about the people and domestic animals that were granted or prohibited access to the open space. I noted land uses mentioned in the documents, including recreation, agriculture, grazing, mining, and other extractive land uses. When specified, I recorded whether land uses were restricted to certain areas or during certain times of the year. I also recorded any rules dictating how land uses are carried out in the protected space, including irrigation, pesticide, and herbicide regulation. I noted any mention of the construction of new structures and buildings, fences, roads, and trails, and any rules regarding maintenance or replacement of existing structures. I collected any information included in the management documents on habitat modification and land management practices in the open space; these activities could include weed control, monitoring, disturbance, restoration, and human-wildlife mitigation. In addition to recording specific stewardship activities and land uses that were permitted, required, encouraged, or prohibited, I also noted any additional recommendations regarding the implementation of those activities (Appendix 2).

Data Analysis

I used a two sample t-test of proportions to determine whether the proportion of CDs with management documents differed between counties with CD ordinances that did or did not require a management document (Reed et al. 2014). I determined whether the document included a stated conservation value of the land, and calculated the proportion of documents that included each stated value. I then analyzed the content of easements and management plans by calculating the proportion of documents that prohibited, permitted, encouraged, or required any items on the list of stewardship activities and land uses (Appendix 1). I determined which activities were most often addressed in order to identify trends in management plan content and identify stewardship activities that are lacking or poorly addressed in these plans.

RESULTS

I obtained county record files for 296 CDs, or 98% of all of the CDs recorded in the six counties. Of the records that were unavailable, two files were being held at an attorney's office for litigation purposes and four were missing for unknown reasons.

Stewardship and Management Documents

A total of 214 CDs (69%) collectively had 256 documents on file that provided guidelines or regulations for stewardship of the protected open space: 158 conservation easements (52% of CDs), 75 habitat/land/outlot management/stewardship/use plans (25%), 9 weed management/control plans (3%), 6 wildlife conservation/mitigation plans (2%), 5 forest management/stewardship plan (2%), 2 agricultural management plans (1%), 2 pasture management plans (1%), 2 owners association regulation/restrictions documents (1%), 1 archaeological easement (0.3%), 1 deed of development rights (0.3%), and 1 trail easement (0.3%). Three of the six counties had ordinances that required a management plan or conservation easement: Boulder County, Larimer County, and Routt County. The proportion of CDs with management documents differed widely among counties, and counties with an ordinance that required a management plan or conservation easement had significantly higher proportions of CDs with management documents on file than those without requirements for management documents ($\chi^2 = 75.3$, $p<0.001$). Larimer County (82%; n=80) and Boulder County (81%; n=116) had the greatest proportions of CDs with management documents. Approximately 40% of the CDs in Chaffee County (n=8) and Routt County (n=6) had management documents. Only 25% (n=4) of the CDs in Douglas County included a management plan, and there were no management documents for any of the CDs in Mesa County.

Over two-thirds (71%) of the management documents did not state a reason for preserving the open space. Among documents that stated such a reason, the majority of documents listed scenic/aesthetic values (78%), open space values (76%), and/or agricultural values (65%). Natural values (55%), ecological values (34%), and wildlife/wildlife habitat values (28%), environmental values (12%), and water resources (9%) were listed less frequently in documents with stated preservation reasons. Finally, recreation, rural character, geological features, and flood drainage were all mentioned in less than 6% of the documents that listed reasons for preserving the open space.

Development and Infrastructure

The documents addressed a wide variety of stewardship activities and land uses, and several items were addressed much more often than others. Most management documents (84%)

permitted or prohibited development or infrastructure in the open space. A majority of documents (73%) provided guidelines or regulation regarding 22 different buildings, structures, and development-related activities (Figure 1; Appendix 3). Among documents that addressed development, the majority (75%) allowed non-residential structures to be built on the parcel, including 70% that allowed agricultural structures to be built. A majority (72%) of these documents prohibited subdivision of the land, and many documents also prohibited building residential dwellings in the preserved areas (66%), or the expansion of structures and pavement that exceed 10 acres or 10% of the total area of the parcel (55%). Only 28% of the documents that addressed development specifically prohibited the construction of any additional buildings or structures on the parcel.

A smaller proportion of documents (28%) included rules regarding the construction and maintenance of fences, roads, utilities, and other infrastructure within the open space (Figure 2; Appendix 4). The vast majority (94%) of the documents that regulated infrastructure permitted the building or repair of fences in the open space. Several of these documents restricted the type of fencing allowed; 25% only permitted fencing that was "wildlife-friendly" or did not inhibit the movement of wildlife through the property, and 18% only permitted fencing in certain areas, including the interior or exterior of the open space, or as protection around a wetland. Other infrastructure development that was most often mentioned included the construction of new paved roads and trails (prohibited by 32% of the documents that regulated infrastructure) and utilities (prohibited by 11% and permitted by 11% of the documents that regulated infrastructure).

Land Use and Activities

A majority (61%) of the documents had regulations or guidelines regarding land uses and activities in the open space. Seventy-five land uses and activities were mentioned in the management documents (Figure 3, Figure 4). Agriculture was the most common land use mentioned, and it was permitted by 71% of the management documents that regulated land uses and activities (Figure 3). Of the documents that permitted agriculture, 39% allowed agriculture as a general term, 38% specifically allowed irrigated agriculture, and 6% allowed tree farming (Appendix 5). Livestock grazing was the second most common land use mentioned, and it was permitted by 59% of the documents that regulated land uses and activities (Figure 3). Of the documents that permitted livestock grazing, 30% limited the areas within the open space where grazing was permitted, 26% limited the number or type of species permitted in the open space, 23% required that grazing occur only when the open space vegetation was in a good condition, and 21% required or encouraged rotational grazing or other sustainable grazing management (Appendix 5). Other land uses commonly mentioned in the management documents included storing or dumping trash or hazardous materials (prohibited in 26% of the documents that regulated land uses), commercial activity (prohibited in 18% of the documents that regulated land uses), and mining (prohibited in 16% of the documents that regulated land uses).

Specific types of passive, or non-motorized, recreation were permitted in 33% of the management documents that regulated land uses and activities (Figure 4). Most commonly, these documents permitted activities such as hiking, horse-riding, bicycling, and snowshoeing, and 30% of the documents that allowed passive recreation restricted these activities to trails or certain areas of the open space. Recreation, used as a general term, was permitted by 15% of management documents that regulated land uses and activities (Appendix 6). Among documents that regulated land uses and activities, a small proportion (7%) of the documents prohibited certain types of passive recreation, including hiking and snowshoeing. A larger proportion (20%) of the documents that regulated land uses prohibited active, or motorized, recreation, while 7% permitted this type of use. Hunting was mentioned less often than other types of recreation, and was permitted in 11% and prohibited in 8% of the documents that regulated land uses and activities.

Habitat Modification and Management

One-third (33%) of the management documents mentioned open space habitat modification and management. These documents included a number of items regarding vegetation management (Figure 5), monitoring and education (Figure 6), and wildlife habitat, disturbance, and wildlife-human conflict (Figure 7). Among documents that mentioned habitat modification and management, a majority (64%) required that the open space be managed in order to control noxious weeds. Of these documents, 24% permitted chemical and mechanical control of weeds, and 30% encouraged selective grazing to manage vegetation (Appendix 8). A small proportion (34%) either encouraged or required the re-seeding or planting of vegetation in disturbed areas. Over one quarter of these documents (30%) included recommendations to decrease the use of chemicals in the open space, including grazing by certain species, and mowing and grass maintenance to lessen dependence on chemicals for weed control (Appendix 8). A large proportion (58%) of the documents that mentioned habitat modification and management also encouraged that landowners decrease or prevent soil erosion.

A small number (15%) of the documents that regulated habitat modification and management mentioned monitoring and education activities within the CDs, including 9% which require continued monitoring of the CD open space (Figure 6). A few of these documents (12%)

required that the open space be managed using a management plan, and 6% of the documents mentioned education for CD residents and landowners (Appendix 8). Of the documents that mentioned education, the majority (60%) required that educational brochures on “living with wildlife” be made available to homeowners at closing. A small number documents also mentioned stewardship activities and land uses relating to resources and disturbances that may impact wildlife in the open space (Figure 7), including the removal of trash from the open space (9%), the introduction of non-native species (9%), and prohibition of feeding, baiting, or otherwise attracting wildlife (6%) (Appendix 9).

Open Space Access

Information about human and domestic animal access of the open space was mentioned least frequently (18%) (Figure 8). Of the management documents that addressed access, the majority (72%) prohibited public (non-resident) access in the open space, whereas 6% allowed the public to access certain trails on the property (Appendix 10). There were rules regarding access of the open space by domestic dogs and cats in 50% of these documents. Access to the open space by CD residents was only mentioned in 11% of these documents, and these documents all limited resident access to the open space during certain times of the year.

DISCUSSION

More than two-thirds (69%) of the 302 CDs that I examined had documents on file that included guidelines and regulations for stewardship of the protected land. The presence of management documents was uneven across counties, and counties that required a management plan or conservation easement had a higher proportion of CDs with management documents on file. A majority of CDs in both Larimer County and Boulder County had management documents, while no management documents were on file for CDs in Mesa County. Over two-thirds (71%) of the management documents did not state the conservation value of the land, and documents that included these values most often listed scenic/aesthetic, open space, and agricultural values rather than ecological or wildlife-related values. Certain land uses and stewardship activities were consistently mentioned, while others were rare or missing. Regulation regarding subdivision of the land and the construction and extent of residential and non-residential structures were most consistently included in management documents. Land uses such as agricultural production and livestock grazing were also mentioned in a large proportion of the documents, and these uses were more often permitted than prohibited. Habitat management activities that were mentioned in the management documents were largely focused on noxious weed control and soil erosion. CD management documents rarely mentioned issues relating to wildlife habitat improvement, species-specific monitoring and management, homeowner education, and access to the open space by domestic pets.

Biodiversity conservation is only one of the many goals that can drive the implementation of CD subdivisions. Often, CDs are used to preserve agricultural production, cultural and archaeological resources, recreation, and aesthetic values for homeowners (McMahon 2002). While it is often assumed that CD will benefit wildlife (Arendt 1996; Theobald et al. 1997), the other management goals and objectives of developers and landowners may result in CDs that contribute limited value to regional conservation (Austin & Kaplan 2003; Lenth et al. 2006; Milder 2007). The stated reasons for preserving the open space that were included in the management documents demonstrate that human uses and enjoyment are often prioritized over wildlife conservation. Values associated with human uses, such as scenic and agricultural values, were far more prevalent (65-78% of documents with stated reasons for preservation) than those relating more closely to conservation goals, such as wildlife, ecological, or environmental values (12-34%). Comparing the content of management plans to recommendations and empirical data about wildlife conservation in these types of developments can help illuminate the major gaps that might limit the ability of CDs to achieve effective wildlife conservation. This knowledge can be used to develop goals and strategies to improve the management plan content for the stewardship of future CDs (Table 1).

Several studies have noted the importance of protecting a large proportion and contiguous area of the CD against development (Lenth et al. 2006; Milder 2007, Farr et al. Chapter 1). Specifically, species composition is often impacted within a "zone of influence" immediately surrounding a house on the landscape (Bock et al. 1999; Odell et al. 2003; Glennon & Kretser 2013). In these areas, human-commensal or habitat generalist species outcompete native or sensitive species (Erz 1966; Blair 1996; Marzluff et al. 2001). A majority of the management documents that I examined prohibited subdivision and certain types of development in the open space, which is not surprising given that protecting land from intensive development is a basic goal of CD and a common requirement of CD ordinances (Pejchar et al. 2007; Reed et al. 2014). However, almost half of the management documents permitted agricultural land uses and livestock grazing. While these types of land uses can provide habitat for many types of species, there are concerns that soil erosion, water pollution, and habitat destruction associated with certain types of agricultural practice can seriously impact local wildlife communities (Crosson & Ostrov 1990; Freemark 1995; Foley 2005). Livestock may also have a disproportionately large effect on wildlife communities due to their tendency to congregate near water and in nutrient rich areas such as riparian zones (Fleischner 1994). However, if managed correctly, livestock grazing can have a positive effect on plant and animal communities by acting as a form of disturbance that mimics the historic disturbance regimes of ecological systems originally reliant on bison grazing (Jones & Bock 2002). Unregulated agriculture and grazing may limit the conservation effectiveness of CDs. For example, human-sensitive mammal species richness in Northern Colorado CDs was negatively related to agricultural land uses (Farr et al. Chapter 1). It may be problematic that only a few documents regulate farming practices or limit the intensity and extent of grazing in CD management documents (Figure 3, Appendix 5).

The composition and structure of open space plant communities have been identified as being among the most important factors that influence the conservation value of CDs (Lenth et al. 2006; Pejchar et al. 2007; Hostetler & Drake 2009; Farr et al. Chapter 1). CDs inherently include the construction of houses and roads, which can often introduce and spread exotic species into the landscape (Trombulak & Frissel 2000). Maintaining native vegetation is key for increasing the ecological function in lands adjacent to residential areas (Mills et al. 1989; Bormann et al. 1993; Marzluff & Ewing 2001), and several authors recommend that indigenous plant species be maintained or restored in areas of the CD disturbed by construction activities (Mckinney 2006; Pejchar et al. 2007). Almost one-fourth (21%) of all CD management documents encouraged or required that noxious weeds be controlled or eliminated. A smaller proportion (11%) addressed seeding or planting vegetation in the open space, and only 5% encouraged the use of native plants when revegetating the area. A lack of guidance on how to maintain and restore native plant communities in the open space may negatively affect habitat quality for wildlife species (Farr et al. Chapter 1).

Native plant communities are often successfully maintained with management that mimics historic levels of disturbance and promotes important ecological processes (Davies et al. 2009). It has been hypothesized that CD open space would provide higher quality habitat if managers used tools such as prescribed burning and rotational grazing to mimic historic disturbances (Lenth et al. 2006; Milder 2007; Hostetler & Drake 2009). These types of management practices were seldom mentioned in the management plans (11%). Greater attention to the variety of strategies that can promote native plant health may improve CD management. The preservation of certain habitat features, such as snags, shrubs, and wetland marshes, can also provide important roosting and nesting structures for many birds and mammals (Ehrlich et al. 1988; Farr et al. Chapter 1). These features were rarely mentioned (7%) in management plans, and recommendations were disparate when they were included (Appendix 2). For example, equal numbers of plans required that snags be removed and recommended that snags be maintained.

Disturbances by humans and their pets can negatively impact animal communities by increasing flight and vigilance behaviors or changing habitat use patterns (Mainini et al. 1993; George & Crooks 2006; Reed & Merenlender 2008; Ordeñana et al. 2009). Cats and dogs can also negatively impact wildlife communities by preying on songbirds, small mammals, amphibians, and reptiles (Crooks & Soulé 1999; Odell & Knight 2001; Baker et al. 2005; Beckerman et al. 2007). CD management documents rarely restricted resident and pet access to the open space. A large majority (91%) of the documents did not mention domestic pets. It is possible that free-roaming domestic animals access the open space regularly in these CDs, especially given that free-roaming domestic dogs were documented at over half (57%) of the CDs examined in Chapter 1 (Farr et al. Chapter 1). A small proportion of documents regulated recreation in the open space, and only 12% prohibited motorized recreation. While use restrictions were rare, documents that prohibited use in certain areas or at certain times had clear wildlife conservation objectives. For example, recreation was restricted at certain times of the year in one CD to decrease disturbances to elk (*Cervus canadensis)* when they were calving, and one CD restricted access to Sandhill Crane (*Grus canadensis*) habitat. Many CD residents value the recreational opportunities provided by the open space in their neighborhood, but also take pride in the wildlife they observe; clearly explaining and stating reasons for any restrictions on access may improve support and compliance with the rules.

One potential reason why CDs do not achieve their full conservation potential is that the protected land is often managed by HOAs or residents that lack the knowledge or skills to monitor and manage it effectively (Milder 2007; Youngentob & Hostetler 2005). In many cases, CD residents may not appreciate or understand the need for stewardship and monitoring. For example, a study by Youngentob and Hostetler (2005) found that CD residents had similar or lower awareness and attitudes regarding environmental issues than residents of traditional subdivisions. Monitoring plant and animal species within a protected space is a participatory way to inform effective stewardship and increase ecological knowledge (Chape et al. 2005; Kiesecker et al. 2007); however, only a small proportion (9%) of the documents encouraged or required this type of ongoing monitoring. Effective management may also be limited by a lack of long-term funding (Reed et al. 2014; Feinberg et al. 2015). However, very rarely (2%) did management documents address funding dedicated to stewardship of the open space. Of course, even if funding is not explicitly mentioned in the management plan, it is possible that this type of support is available. Regardless, clear identification of funding sources allocated to open space management is more likely to ensure long-term support for stewardship activities (Table 1).

Education initiatives and consultation with conservation organizations or government agencies regarding open space management are two ways to increase landowner knowledge and effective CD stewardship (Milder 2007; Thompson 2004) (Table 1). These strategies were rarely mentioned in the management plans; they each appeared in only 2% of the documents. Hostetler and Drake (2009) believed that a robust education program was key for creating CDs that were effective at preserving wildlife. They recommended that an active education program should thoroughly describe best management practices and address wildlife issues, and they suggest that community websites and signage will help visibly encourage stewardship of the land long after an individual buys a home in the CD (Hostetler & Drake 2009). However, very few of the management documents encouraged or required active education regarding CD stewardship. Of those documents that mentioned education initiatives, the majority (75%) merely required that educational brochures be made available to homeowners when they purchased a house in the CD.

Conclusion

In order for CD to achieve its potential as an effective private land conservation strategy, developers and homeowners need to implement best practices during the design, construction and stewardship phases of a CD subdivision (Hostetler & Drake 2009). However, current CD efforts tend to focus on CD design, while long-term stewardship is neglected (Hostetler & Drake 2009; Hostetler 2012; Feinberg et al. 2015). This study identifies the current strengths and weaknesses in the documents that guide stewardship of CD subdivisions in Colorado. Including requirements for a long-term management plan in CD ordinances is an important first step to encourage long-term stewardship. However, management plans will fall short of achieving biodiversity conservation objectives unless they include critical guidelines and regulation that address important conservation issues, enforcement of plan implementation, and resources to support stewardship activities (Table 1). Land-use goals will vary depending on social, economic, and biophysical contexts, and management plans should provide specific recommendations to decrease negative impacts to species and provide quality habitat for wildlife communities (Table 1). Plans should also specifically address vegetation and habitat management, access to the open space by domestic pets, homeowner education, long-term monitoring, and funding for continued management (Table 1). If the values, goals, and management of CDs currently neglect or impede conservation objectives, adding this content to management plans may ensure that CD achieves its potential as an effective tool for conservation on private lands.

TABLES

Table 1. Current limitations of CD management plans and conservation easements (n=256) and recommendations for adding or altering content to increase CD's ability to achieve wildlife conservation objectives.

Current limitation	Recommended improvement
Agricultural production was permitted or required in 55% of management documents, but fewer than 25% limited its extent, regulated herbicide/pesticide use, or encouraged prevention of soil erosion	Include specific regulation for agricultural activities that could impact water quality and soil erosion, and provide best management practices for sustainable agriculture
Fewer than 30% of the documents that permitted livestock grazing limited the number of species, or require sustainable grazing practices	Specify the species and maximum number of animals that should graze the open space. Encourage or require rotational grazing and other sustainable grazing practices. Limit livestock access to ecologically sensitive areas in the open space
Only 11% of documents encourage or require seeding, planting, or managing vegetation in the open space and only 5% encourage the use of native plants when revegetating	Require that the CD maintain native plant cover in the open space and restore or replant areas that have been disturbed. Discourage landscaping or planting invasive exotic plants
Fewer than 7% of management plans mention habitat features that are important to wildlife, and some documents required removal of important features such as snags	List important habitat features that can benefit targeted wildlife, and include recommendations for preserving these features on the landscape
Fewer than 10% of documents mention domestic pets	Prohibit access to open space by free-roaming domestic pets
Education initiatives and consultation with experts were mentioned in only 2% of management documents	Establish active outreach programs. Encourage or require consultation with local agencies and experts to provide advice regarding best practices for management
Fewer than 10% of documents required long-term monitoring	Require long-term monitoring of the open space and adaptive management to adjust to changing conditions
Only 2% of management plans included a description of how stewardship would be funded	Clearly identify funding sources to ensure long-term support for stewardship activities.

FIGURES

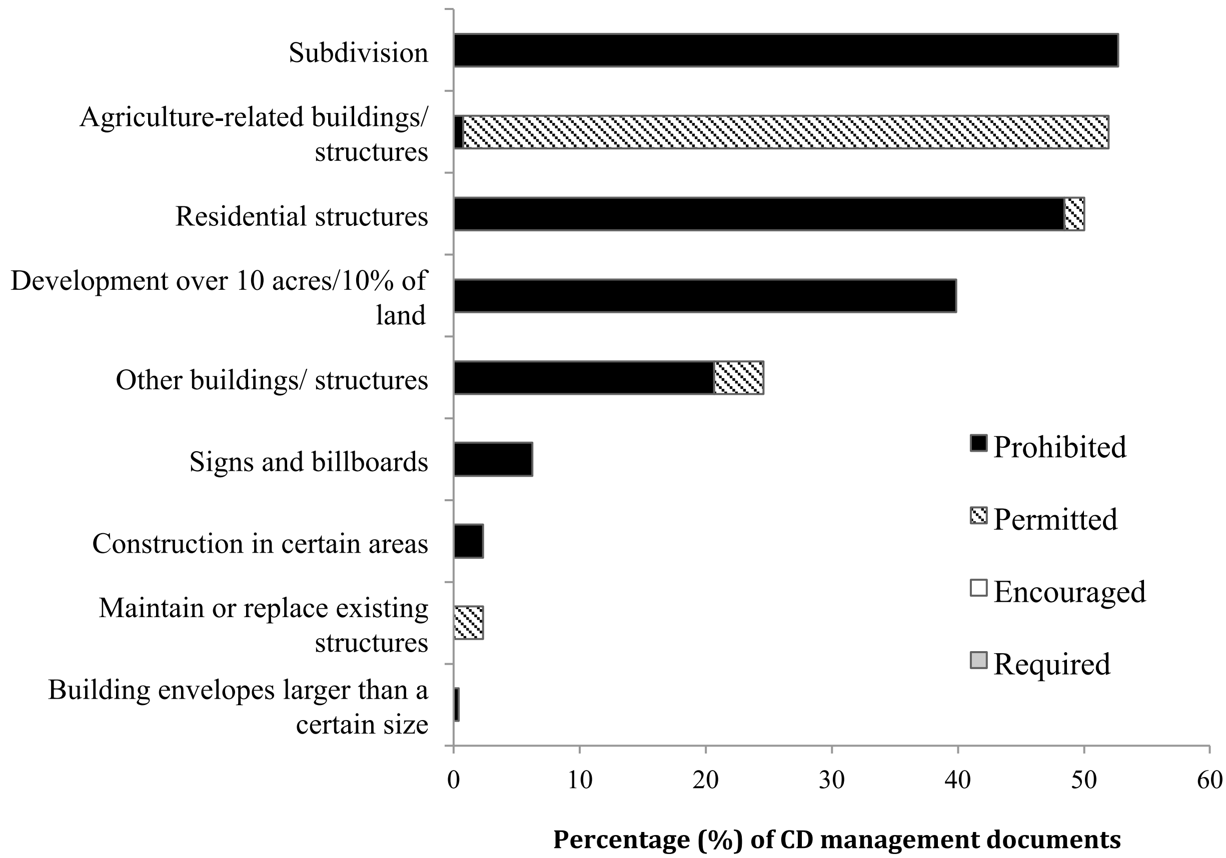

Fig. 1. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with the development, construction and maintenance of structures in the open space.

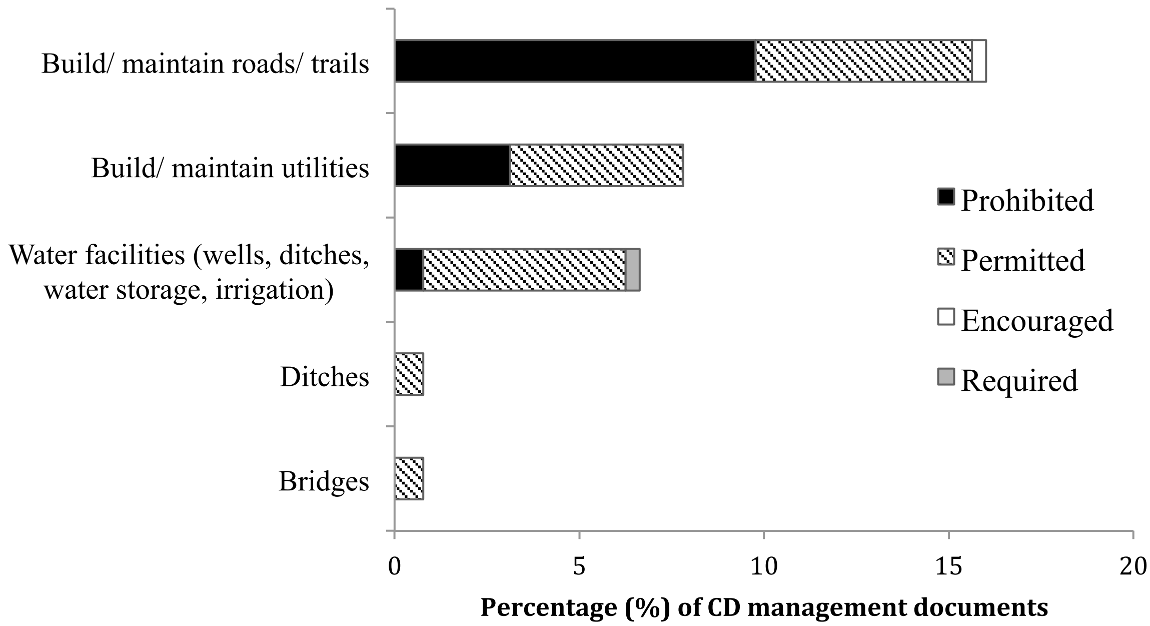

Fig. 2. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with the development, construction and maintenance of infrastructure in the open space.

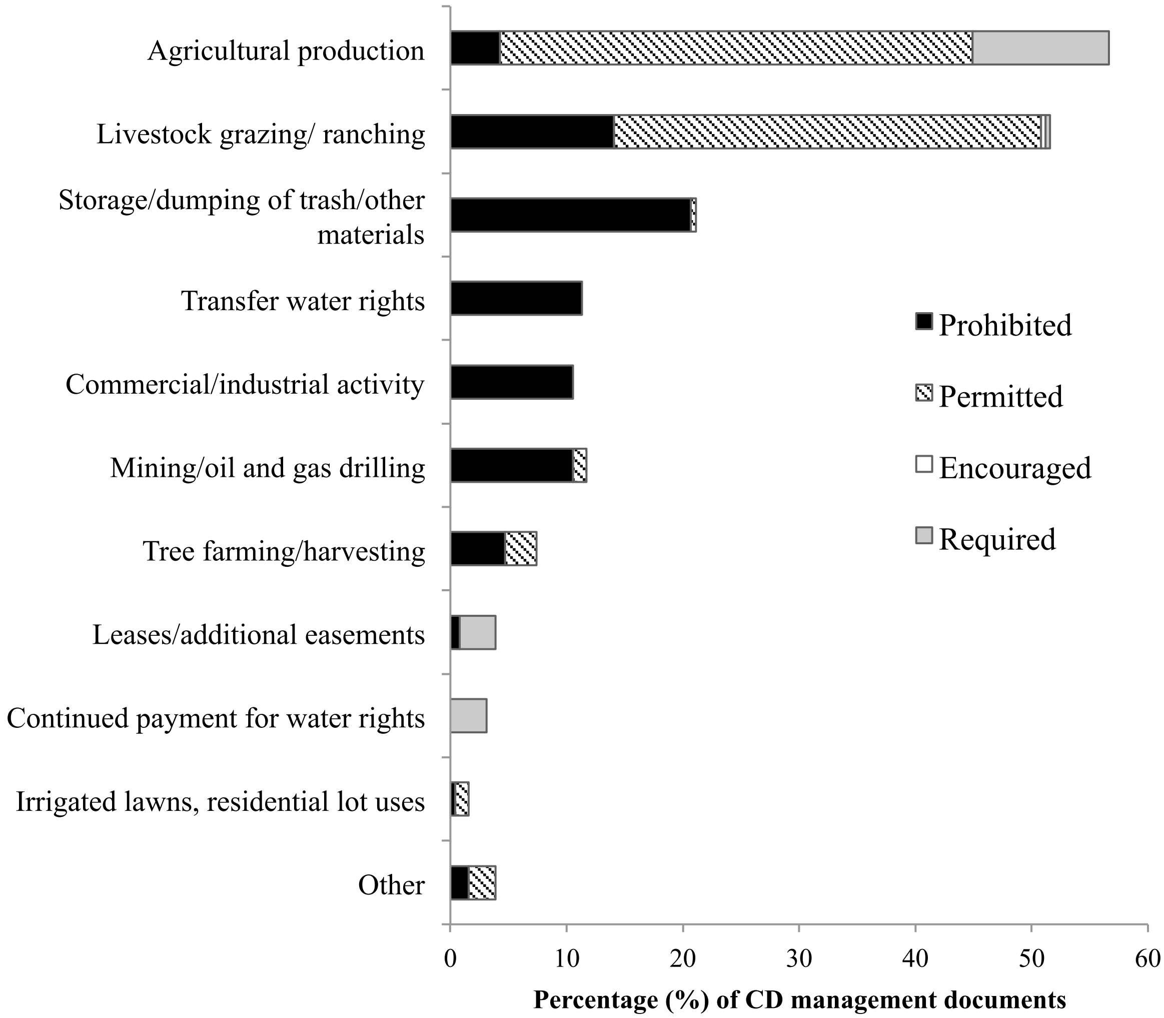

Fig. 3. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with agriculture, grazing, mining, and other extractive land uses in the open space.

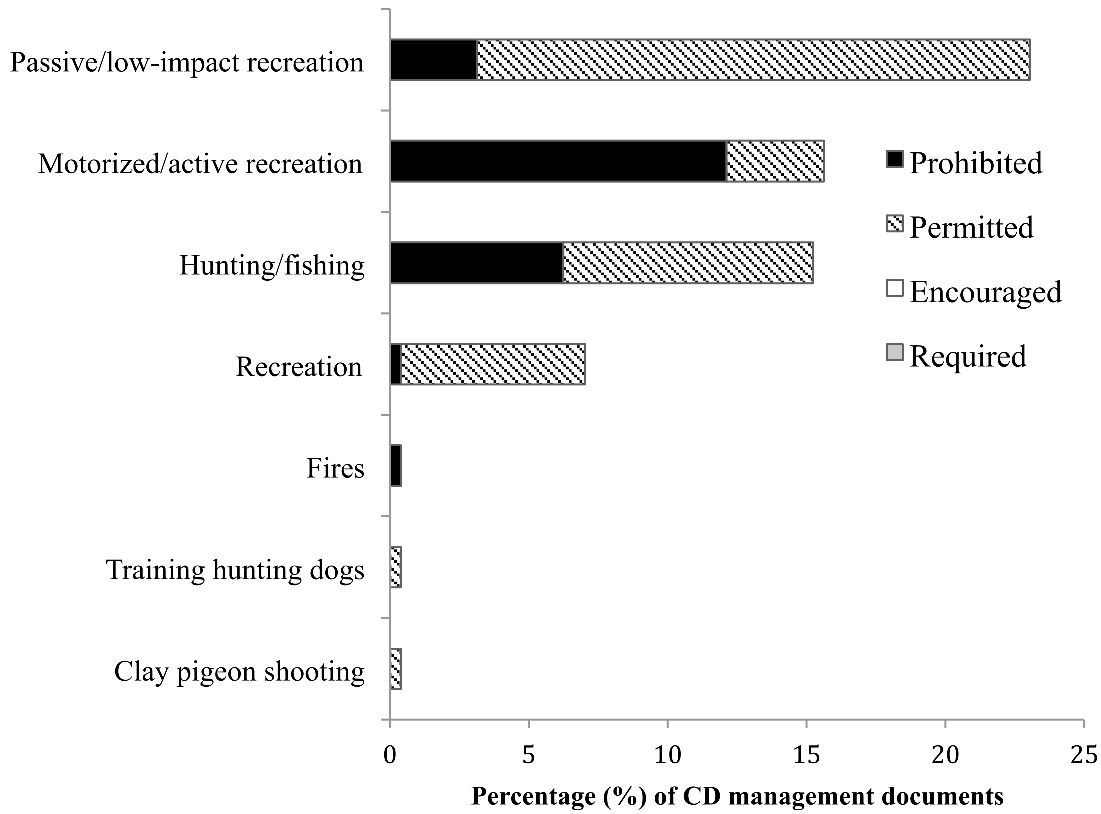

Fig. 4. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with recreational land uses in the open space.

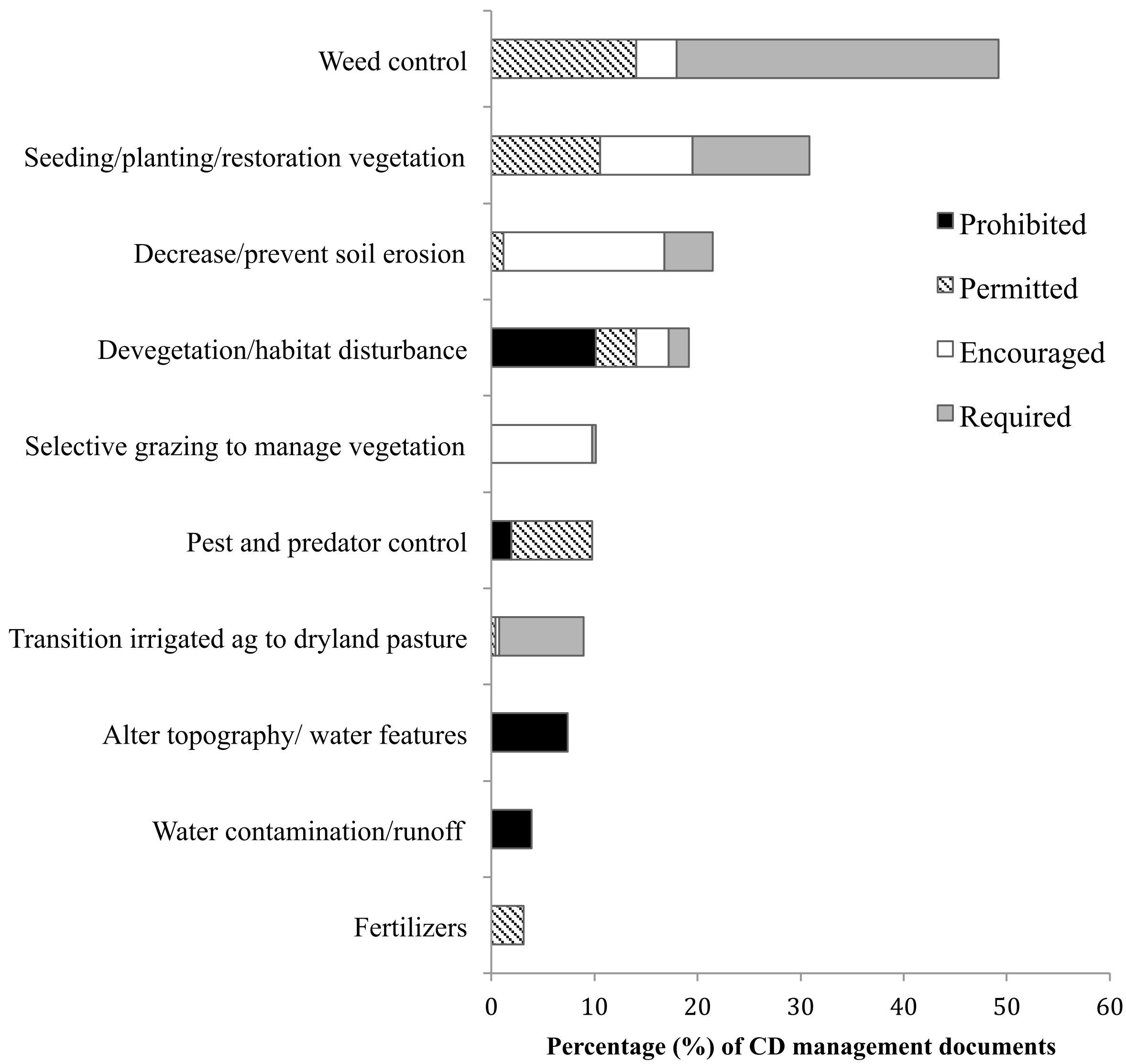

Fig. 5. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with vegetation management in the open space.

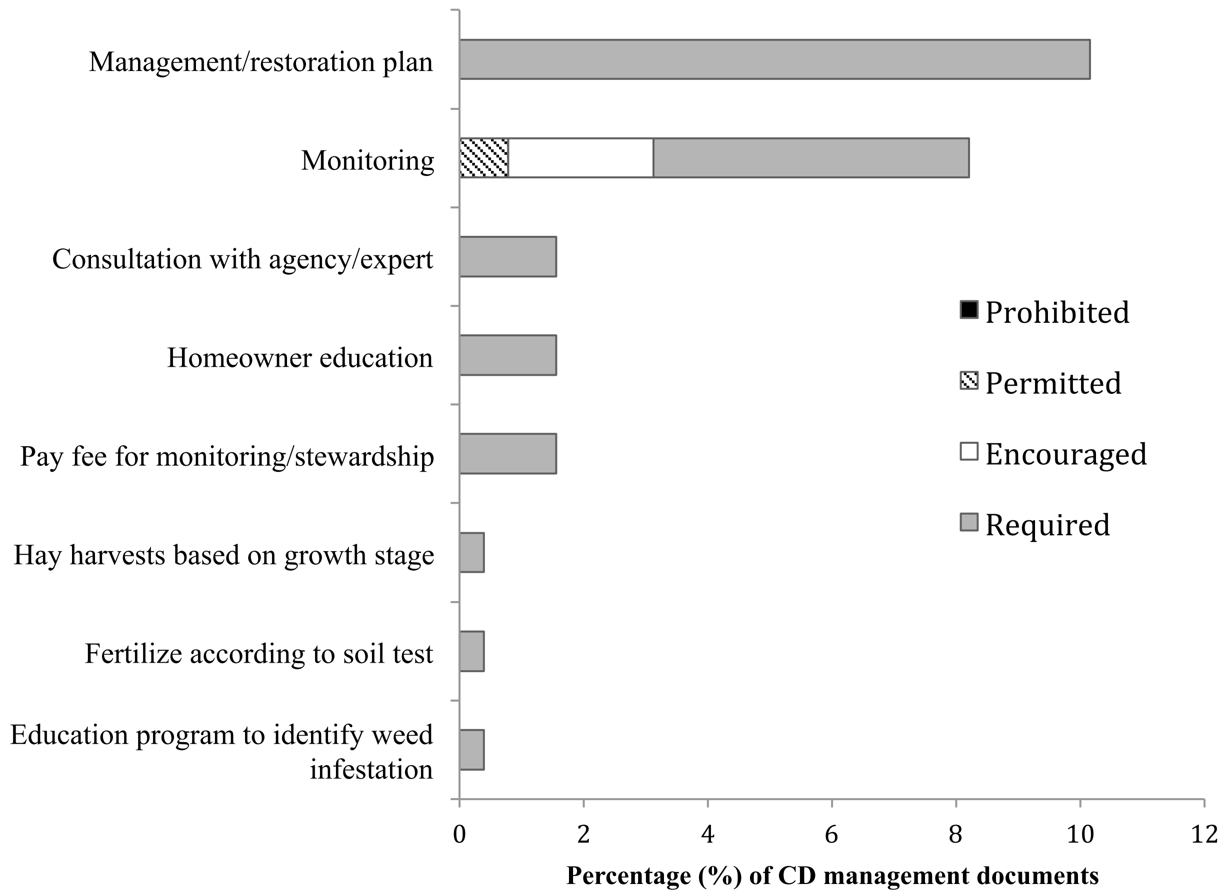

Fig. 6. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with education, management, and monitoring of the open space.

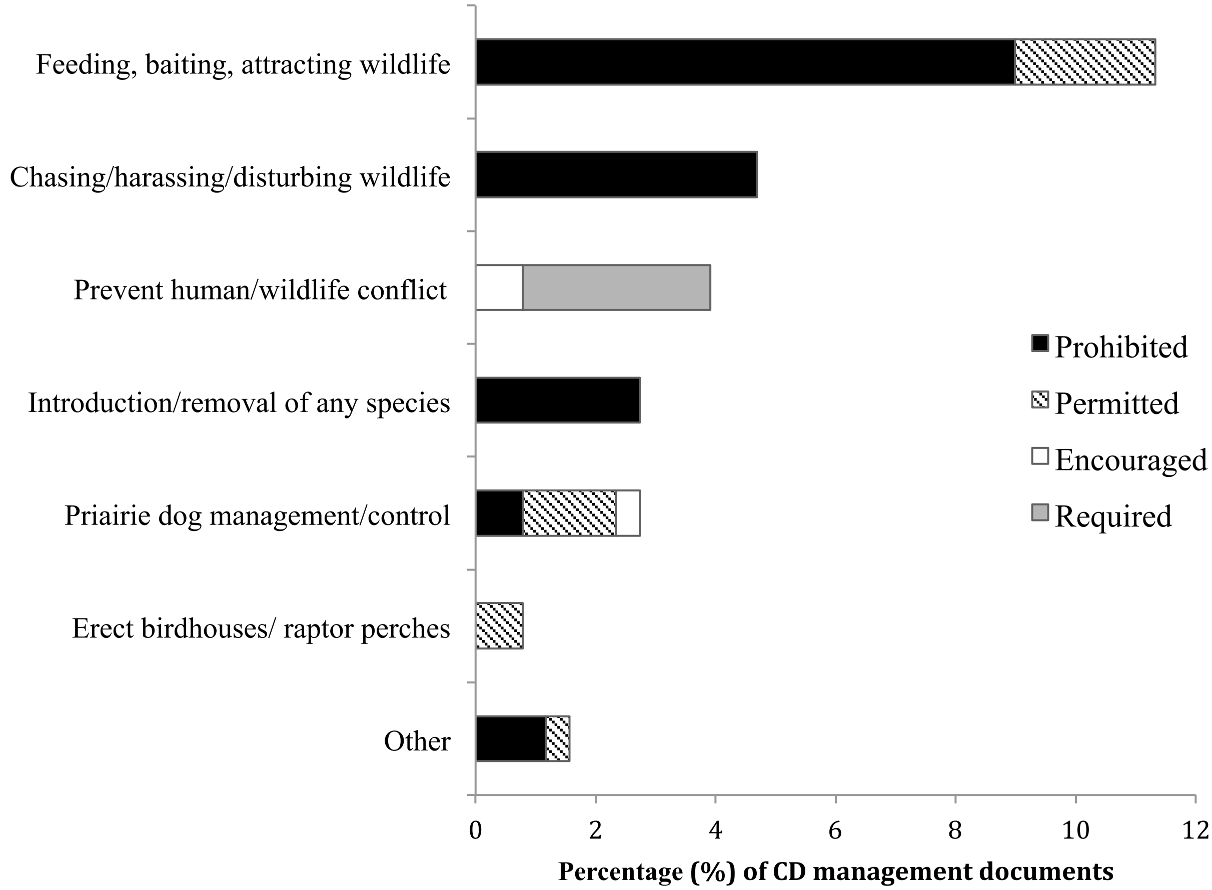

Fig. 7. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with wildlife habitat, disturbance, and wildlife-human conflict. The "other" category includes setting fires, planting the roads with unpalatable plants, activities detrimental to water quality, throwing rocks over the cliff, exposed bulbs, vegetable gardens, and all-night light.

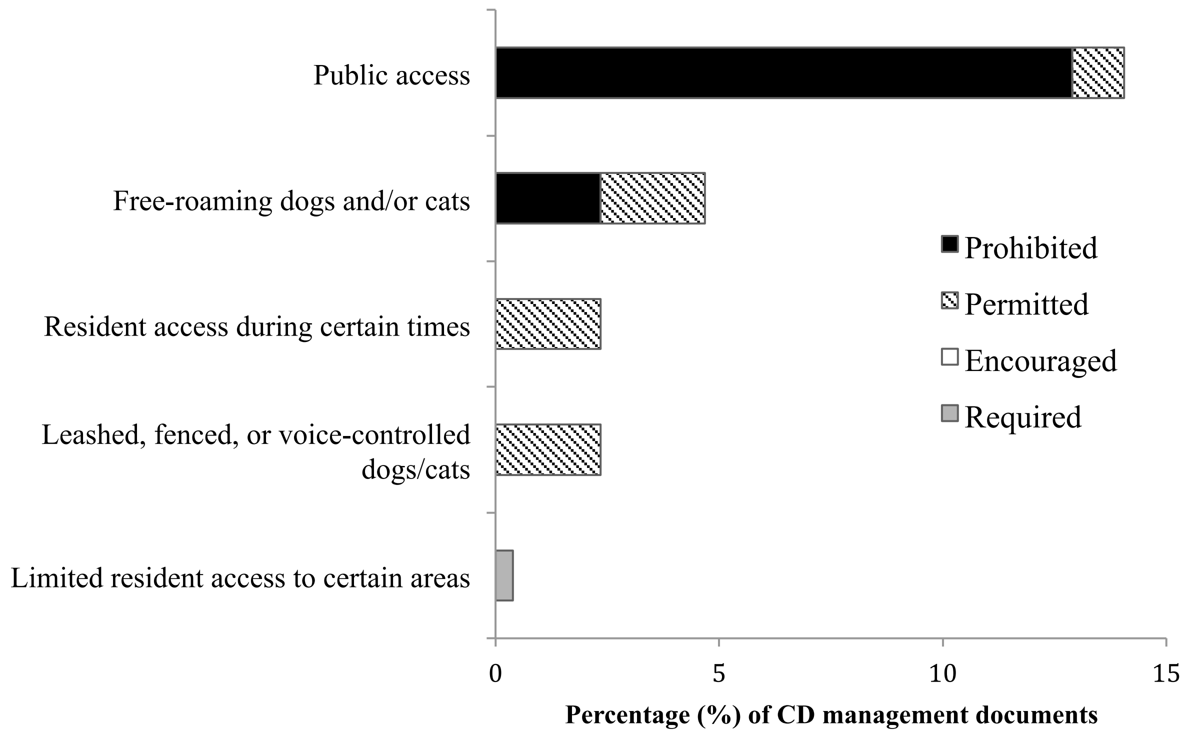

Fig. 8. CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with access to the open space.

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APPENDICES

Appendix 1: The systematic content analysis used to determine the presence or absence of a list of land uses and stewardship activities in management plans or easement documents for CDs in six Colorado counties.

I. Document Overview:

1. Name:

2. Type:
    - Easement
    - Management plan
    - Other [specify]

3. Date CD established:

II. Document Content:

1. Is there a stated reason for preserving the land, or value of the land for conservation? [Yes/No]
    a. If yes, what is the stated value?
        - Scenic
        - Wildlife habitat
        - Open Space
        - Other [specify]

2. Which of the following elements are required to be included in the document? (Select all that apply.)
    - Establishment of funding source
    - Staffing needs
    - Monitoring of conservation targets
    - Management of conservation targets
    - External approval or review of management plan
    - External enforcement of management plan
    - Other [specify]

3. Which of the following land uses or activities are mentioned in the document? If mentioned, indicated whether they are permitted, required, encouraged, prohibited in the CD? Note any specific requirements, seasonal restrictions, or other details about the activity or land use. (i.e. For each item, indicate: [Mentioned/ Not mentioned] and [Permitted/ Required/ Encouraged/ Prohibited] [seasonal restrictions/ additional details/ requirements])
    a. Access:
        - Access by residents
        - Access by public
        - Pets

b. Activities

- Non-motorized recreation
- Motorized recreation
- Non-consumptive recreation
- Hunting
- Training hunting dogs
- Activities that negatively impact threatened or endangered species
- Off-road Travel
- Discharge of Firearms
- Paintball

c. Development

- Additional buildings and Structures
- Roads
- Parking lots
- Golf courses
- Subdivision
- New utilities
- Fences
- Leases or other agreements
- Feedlots
- Tennis courts
- Swimming facilities
- Athletic fields
- Helicopter pads
- Airstrips
- Trenches
- Storm Drainage Improvements

d. Land uses

- Agriculture
- Grazing
- Timber harvest
- Non-commercial use
- Commercial recreational uses
- Haying
- Commercial or Industrial activity
- Mining
- Dumping of trash
- Storage of vehicles and equipment
- Storage of agricultural products
- Sod farming

c. Management/Stewardship

- Range Management

- Soil Conservation
- Weed control
- Pest species control
- Control of exotic species
- Control of invasive
- Prevention of overgrazing
- Alteration of water features
- Use of fertilizers
- Use of pesticides
- Use of herbicides
- Fire protection
- Prescribed fire
- Habitat restoration
- Native species vegetation
- Supplemental feeding
- Stream bank stabilization
- Erosion control
- Snag removal
- Stream restoration
- Noise restrictions

d. Other [Specify]

Appendix 2. Specific recommendations included in management documents regarding land use, preservation of resources, and other stewardship activities in 214 conservation development (CD) subdivisions in Colorado, USA.

Activity / Resource	**Recommendation**	**# of CDs**
Grazing	Prevent/avoid overgrazing	6
	Monitor vegetation and adjust stocking rates	2
	Reduced stocking/grazing during years of drought	2
	Livestock kept out of water bodies	1
	Avoid devegetation/ disturbance	1
	Graze or mow grass in lots to keep height below 7 inches	1
	Minimum rest period 45-days April 15-June 15, 90 days June 15-October 15	1
	Exclosures for grazing	1
	Supplemental winter feeding for livestock	1
	Wetlands can be grazed, but should remain undisturbed	1
Non-native Species	Avoid introducing non-native species	6
	Remove dwarf mistletoe, prune slightly infected trees	3
	Decrease population of Knapweed	2
	Use combination of methods to combat weeds	2
	Control cattails	1
	Mow, maintain grass to lessen dependence on chemicals for weed control	1
	Eradicate Canadian thistle	1
	Remove Russian Olive trees around wetland area	1
	Avoid introduction/removal of any new species	1
Agriculture	Minimize disturbance	2
	Maintain soil fertility	1
	Minimize impacts of agriculture on residents	1
	Rotate crops and pasture grasses	1
	Don't cut plants at immature stage	1
	Reduce use of commercial fertilizers, pesticides, and herbicides	1
	Vegetative assessment before irrigation water permanently removed	1
Water Resources	Avoid degradation/development of riparian area	8
	Keep foreign debris from collecting in riparian areas	3
	Change drainage to have small shallow pools and wetlands	1
	Construct and maintain drainage in receptor ditch	1
	Reduce water loss	1
	Increase wildlife around ponds/wetlands	1
	Set aside areas for wildlife/wetland	1
Forests	Protect young aspen with fencing	1
	Land management consistent with the historic recreational and forestry uses	1
	Burn slash piles	1
	Maintain snags	1
Disturbances	No alteration of structures with historical significance	3
	Remove excess earth/rocks, tailings from construction, maintenance, repair	2

	Prevent changes to ridgelines	1
	Reasonable steps to prevent third parties from disturbing area	1
Wildlife conflict	Traffic regulations to limit potential collisions with wildlife	3
	Outdoor storage of garbage in bear-proof containers	2
	Minimize potential for elk-human conflict	1
Wildfire	Natural landscaping to reduce wildfire threat	1
	Put in a fuel break	1
Education	Educate homeowners to appreciate and maintain existing vegetation	1

Appendix 3. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with the development, construction and maintenance of structures in the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Subdivision	52.7%	0	0	0
Residential structures	48.4%	1.6%	0	0
Agriculture-related buildings/ structures	0	45.7%	0	0
Development over 10 acres/10% of land	39.8%	0	0	0
Buildings/ structures	13.7%	0.78%	0	0
Signs and billboards	6.3%	0	0	0
Horse stable/ facilities	0.39%	3.9%	0	0
Telecommunication facilities	2.7%	0	0	0
Maintain or replace existing structures	0	2.3%	0	0
Construction in certain areas	2.3%	0	0	0
Barns/Outbuildings in certain areas	0.39%	1.6%	0	0
Helicopter pad, airstrip	1.6%	0	0	0
Non-residential structures (size limit)	0	1.2%	0	0
Playground	0.78%	0.39%	0	0
Cemetery	0.39%	0.39%	0	0
Commercial facilities	0.78%	0	0	0
Recreational facilities	0	0.39%	0	0
Campfire circle	0	0.39%	0	0
Gazebo	0	0.39%	0	0
Building envelopes larger than size	0.39%	0	0	0
Wind turbines	0.39%	0	0	0
Archery/ rifle range	0.39%	0	0	0

Appendix 4. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with the development, construction and maintenance of infrastructure in the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Build/ repair fences	2.7%	12.1%	0	0
Wildlife-friendly fences	0	5.5%	0.39%	1.9%
Water facilities (ditches, water storage, irrigation)	0.78%	5.5%	0	0.39%
Utilities	3.1%	3.5%	0	0
Paved roads/ trails	6.6%	0	0	0
Roads	2.7%	3.1%	0	0
Exterior/ perimeter fencing	0	2.3%	1.17%	0.39%
Maintain existing roads	0	1.9%	0	0
Maintain existing fences	0	1.9%	0	0
Temporary fencing	0	1.9%	0	0
Fences that prevent passage/injury of wildlife?	1.6%	0	0	0
Maintain existing utilities	0	1.2%	0	0
Fences (restricted size, height, area)	0	1.2%	0	0
Trails	0.39%	0.39%	0.39%	0
Fencing in certain areas	1.2%	0	0	0
Bridges	0	0.78%	0	0
Ditches	0	0.78%	0	0
Cross/ internal fencing	0.39%	0.39%	0	0
Fencing house lots	0.78%	0	0	0
Unpaved roads	0	0.39%	0	0
Fencing around gardens	0	0.39%	0	0
Fencing to protect wetland	0	0.390%	0	0

Appendix 5. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with agriculture, grazing, mining, and other extractive land uses in the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Agricultural production	0	20.3%	0	10.9%
Livestock grazing	0.78%	19.9%	0	0.39%
Irrigated agriculture	0.78%	15.6%	0	0.78%
Storage/dumping of trash	13.7%	0	0	0
Transfer water rights	11.3%	0	0	0
Mining	9.8%	0.39%	0	0
Commercial/industrial activity	10.2%	0	0	0
Livestock grazing (limited number/species)	3.9%	4.3%	0.39%	0
Tree farming/harvesting	4.7%	2.7%	0	0
Grazing in certain areas	1.9%	3.1%	0	0
Commercial feed lots, intensive livestock	5.1%	0	0	0
Storing materials, equipment, vehicles	3.9%	0.39%	0	0
Grazing (if grass in good condition)	0	3.9%	0	0
Livestock grazing (good/ rotational grazing)	0	3.5%	0	0
Continued payment for water rights	0	0	0	3.1%
Storing hazardous materials	2.7%	0	0	0
Agricultural leasing	0	2.3%	0	0
Commercial livestock, kennels, poultry	2.3%	0	0	0
Hay meadow	0	1.9%	0	0
Dry crops	0	1.2%	0	0
Annexation	1.2%	0	0	0
Oil and gas drilling (screened from view)	0.39%	0.78%	0	0
Agriculture (areas currently in ag)	0	0.78%	0	0
Haying/mowing (certain areas)	0.78%	0	0	0
Intensive agriculture	0.78%	0	0	0
Sod farms	0.78%	0	0	0
Irrigated agriculture (specified land area)	0	0.78%	0	0
Irrigated landscaped entrance	0	0.78%	0	0
Open space uses	0	0.78%	0	0
Leases/additional easements	0.78%	0	0	0
Use water/pump from wells	0	0.78%	0	0
Minor grazing	0	0.78%	0	0
Septic field	0.39%	0.39%	0	0
Agriculture (certain areas)	0.39%	0	0	0
Agribusiness	0.39%	0	0	0
Agriculture that diminishes conservation value	0.39%	0	0	0
Irrigated lawns	0	0.39%	0	0
Uses typical of residential lots	0.39%	0	0	0
Wildlife habitat	0	0.39%	0	0
Confined livestock in existing corrals	0	0.39%	0	0
Ranching	0	0.39%	0	0
Ranching existing at time of easement	0	0.39%	0	0
Sawmills	0.39%	0	0	0
Stone quarry/mineral extraction	0.39%	0	0	0
Temporary asphalt, concrete	0.39%	0	0	0

Appendix 6. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with recreational land uses in the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Motorized recreational vehicles	7.8%	1.6%	0	0
Passive/low-Impact recreation	0	8.6%	0	0
Hunting	3.1%	4.7%	0	0
Recreation	0.39%	6.3%	0	0
Passive recreation (designated locations)	0	4.7%	0	0
Bicycle riding	1.9%	1.2%	0	0
Irrigated recreation areas	2.7%	0	0	0
Horse riding/animal exercise	0	2.3%	0	0
Leg-hold traps	1.6%	0	0	0
Recreation (restricted times)	0	1.6%	0	0
Camping	1.2%	0.39%	0	0
Hunting for overpopulation/disease management	0	1.2%	0	0
Commercial hunting	1.2%	0	0	0
Snowmobiling	1.2%	0	0	0
Fishing	0	0.78%	0	0
Hunting in restricted areas	0	0.78%	0	0
Hiking/fishing (restricted times)	0	0.78%	0	0
Recreation (doesn't impair ag/conservation)	0	0.78%	0	0
Motor vehicles for maintenance, ag/ranching	0	0.78%	0	0
Motorized recreational vehicles (certain areas)	0	0.78%	0	0
Clay pigeon shooting	0	0.39%	0	0
Training hunting dogs	0	0.39%	0	0
Discharging firearms	0.39%	0	0	0
Educational, scientific research	0	0.39%	0	0
Non-commercial recreation	0	0.39%	0	0
Commercial recreation	0	0.39%	0	0
Picnics	0	0.39%	0	0
Fires	0.39%	0	0	0
Non-commercial paintball (max 3 days/year)	0	0.39%	0	0
Active recreation	0.39%	0	0	0

Appendix 7. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with vegetation management in the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Noxious weed control	0	0	1.9%	20.7%
Decrease/prevent soil erosion	0	0.78%	15.6%	4.3%
Chemical and mechanical weed control	0	8.6%	0.78%	1.2%
Selective grazing to manage vegetation	0	0	9.8%	0.39%
Transition irrigated agriculture to dryland pasture	0	0.39%	0.39%	8.2%
Seeding/planting vegetation	0	1.9%	0.78%	5.1%
Weed control	0	3.5%	1.2%	2.3%
Wildlife habitat and wetland restoration	0	4.3%	1.9%	0.39%
Predator and varmint control	0	5.5%	0	0
Tree cutting for wildfire management, health	0	1.2%	2.3%	1.6%
Alter topography	3.9%	0	0	0
Immediately revegetate disturbed areas	0	0	0.39%	3.5%
Plant native trees	0	0.39%	2.3%	0.78%
Revegetation/landscaping (native species)	0	0.78%	2.3%	0.39%
Alter water features, irrigation courses	3.5%	0	0	0
Fertilizers	0	3.1%	0	0
Devegetation/disturbance	2.7%	0	0	0
Weed-free roadbed gravel, fill material	0	0	0	2.7%
Tree cutting for disease/insect control	0	2.3%	0	0
Devegetation/disturbance (certain areas)	2.3%	0	0	0
Overgrazing	2.3%	0	0	0
Weed-free construction equipment	0	0	0	2.3%
Pesticides and herbicides	0.39%	1.9%	0	0
Biocides to control noxious weeds	0	1.9%	0	0.39%
Contaminate water with agrichemicals	2.3%	0	0	0
Maintain/enhance grassland	0	0.78%	1.2%	0
Restoration	0	0.39%	0	1.2%
Change, disturb, alter conservation values	1.6%	0	0	0
Control runoff	0	0	1.2%	0.39%
Noxious weeds growing uncontrolled	1.2%	0	0	0
Aerial application of biocides	1.2%	0	0	0
Streambank stabilization/restoration	0	0.39%	0	0.39%
Cut/remove snags	0	0.39%	0	0.39%
Plant native wetland plants in riparian area	0	0.78%	0	0
Impacts on wetlands	0.78%	0	0	0
Controlled burns	0	0	0.78%	0
Create open water in wetland	0	0.39%	0	0
Reclaim gravel pit area	0	0.39%	0	0
Install windbreaks	0	0.39%	0	0
Exposed soil with no ground cover	0.39%	0	0	0
Devegated area (more than certain amount)	0.39%	0	0	0
Pesticides and herbicides (certain areas)	0.39%	0	0	0
Buconoid wasps to control flies	0	0.39%	0	0

Appendix 8. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with education, management plans, and monitoring of the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Monitoring	0	0	1.6%	2.7%
Manage using management plan	0	0	0	3.5%
Develop formal erosion plan if erosion increases	0	0	0	2.3%
Pay fee for monitoring/stewardship	0	0	0	1.6%
Develop grazing management plan	0	0	0	1.6%
Provide educational brochures to each homeowner	0	0	0	1.2%
Annual survey/census of wildlife	0	0.39%	0.39%	0
Monitor easement with photo documentation	0	0	0.39%	0.39%
Field inspection for weeds	0	0	0	0.78%
Review management plan at least every 5 years	0	0	0	0.78%
Trapping to study ESA species	0	0.39%	0	0
Adaptive management	0	0	0	0.39%
Grazing advice from extension	0	0	0	0.39%
Pasture management consultation every 5 years	0	0	0	0.39%
Consultation about construction/ ESA species	0	0	0	0.39%
Burrowing owl surveys prior to prairie dog control	0	0	0	0.39%
Trail management plan	0	0	0	0.39%
Cooperation with agency for Bell's Twinpod survival	0	0	0	0.39%
Use soil moisture/ stress tests to inform irrigation	0	0	0	0.39%
Create wetland improvement plan	0	0	0	0.39%
Education program to identify weed infestation	0	0	0	0.39%
Fertilize according to soil test	0	0	0	0.39%
Hay harvests based on growth stage	0	0	0	0.39%
Maintain log of weed management	0	0	0	0.39%
Map leafy spurge distribution biannually	0	0	0	0.39%
Restoration plan	0	0	0	0.39%

Appendix 9. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with wildlife habitat, disturbance, and wildlife-human conflict.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Introduce non-native species (except for grazing)	2.3%	0	0	0
Remove trash	0	0	0.78%	1.6%
Priairie dog management/control	0	1.6%	0.39%	0
Feeding, baiting, attracting wildlife	1.9%	0	0	0
Feeding pets outside homes	1.6%	0	0	0
Hay stored in wildlfie-resistant containers	0	0	0	1.6%
Bird feeders	0	1.2%	0	0
Stockpiling manure and soil bedding	0.39%	0.78%	0	0
Garden compost pile (unless bear-proof)	1.2%	0	0	0
Store garbage outside (unless bear-proof)	1.2%	0	0	0
Remove birdfeeders when absent	0	0	0	1.2%
Spreading composted manure on fields	0.39%	0.39%	0	0
Roadkill disposal on property	0.78%	0	0	0
Disturbing/ removing natural wildlife kills	0.78%	0	0	0
Exposed bulbs and all-night light	0.78%	0	0	0
Loud noises	0.78%	0	0	0
Chasing/harassing/disturbing wildlife	0.78%	0	0	0
Erect raptor perches	0	0.39%	0	0
Birdhouses	0	0.39%	0	0
Vegetable gardens	0	0.39%	0	0
Ponds	0	0.39%	0	0
Hay/alfalfa stored at certain times of year	0.39%	0	0	0
Equipment that produces noise, heat	0.39%	0	0	0
Prairie dog control if burrowing owls present	0.39%	0	0	0
Introduction/removal of any species	0.39%	0	0	0
Poison grain to manage prairie dogs	0.39%	0	0	0
Refuse burning	0.39%	0	0	0
Remove natural resources (without permission)	0.39%	0	0	0
Setting fires	0.39%	0	0	0
Throwing rocks/ debris over the cliff	0.39%	0	0	0
Negatively impact ESA species or habitats	0.39%	0	0	0
Plant roads with unpalatable plants	0	0	0	0.39%
Activities detrimental to water quality	0.39%	0	0	0

Appendix 10. Percent (%) of CD management documents that prohibited, permitted, encouraged, or required land use and stewardship activities associated with access to the open space.

Land Use/Stewardship Activity	Prohibited	Permitted	Encouraged	Required
Public access	12.9%	1.2%	0	0
Free-roaming dogs and/or cats	2.3%	2.3%	0	0
Resident access during certain times	0	2.3%	0	0
Leashed, fenced, or voice-controlled dogs/cats	0	2.3%	0	0
Limited resident access to certain areas	0	0	0	0.39%