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Balancing housing growth and land conservation: Conservation development preserves private lands near protected areas

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HIGHLIGHTS

- We document 343 conservation developments (CDs) in 13 Colorado counties, protecting 19,744 ha of open space.
- CDs occupied <1% of land area, but comprised 11% of private protected land.
- The majority (76%) of CDs are adjacent to protected areas.
- Targeted placement of CDs and coordinated management across CDs and protected areas will increase their conservation benefits.

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ABSTRACT

Housing development has emerged as a primary driver of land-use change around the world. In the United States, there is particular concern about low-density residential development on rural lands, which often occurs in places with abundant natural amenities. Conservation development (CD), housing development that incorporates protected open space, has emerged as a tool that can accommodate development and achieve land protection, potentially forming networks with existing protected areas. To assess how these developments contribute to housing and conservation at the landscape level, we gathered data on 343 CDs in 13 counties throughout the State of Colorado, U.S.A., including the number, location, and open space configuration of these housing developments. We found that although CDs comprise a small proportion of housing (4% on average), they account for a mean of 11% of privately owned protected lands, and they are often located in close proximity to protected areas (on average <400 m). A majority of these developments (76%) are immediately adjacent to at least one protected area, most commonly the protected open space of other CDs, and more than one-third (33%) of these developments are adjacent to two or more protected areas with different ownership. We conclude that CDs are poised to contribute to conservation at the landscape level in Colorado, given their proximity to protected lands. However, here and elsewhere, strategic placement of these housing developments and well-coordinated open space stewardship will be important if they are to serve as functional parts of protected area networks.

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1. Introduction

Globally, housing development and residential land consumption per person is rising with industrialization (Bradbury, Peterson, & Liu, 2014), with public protected areas often insufficient to conserve biodiversity and ecosystem functioning in the face of this private land conversion (Kamal, Grodzińska-Jurczakn & Brown, 2015). In the United States (U.S.), residential development in rural areas has expanded rapidly over the past 40 years, most of it in the form of low-density housing (6–10 homes/km^2) (Brown, Johnson, Loveland, & Theobald, 2005; Radeloff et al., 2005). The transformation of rural private lands is driven by multiple factors, including people's preferences for living near natural amenities and small towns, the lower cost of housing in these areas, greater willingness to commute long distances, and increasing telecommuting and

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mobility with retirement (Gosnell & Abrams, 2011). To create conventional housing developments, land is subdivided into large lots, each with a home, and no land is protected, although building is prohibited in some areas for regulatory (e.g., wetlands) or physical reasons (Pejchar, Morgan, Caldwell, Palmer, & Daily, 2007). As low-density housing has spread across the U.S., conservationists and planners have raised increasing concerns about its potential environmental impacts, particularly when housing expands in forest or wildland vegetation and/or on the periphery of publically protected lands (Hansen et al., 2005).

Residential development and associated infrastructure such as roads and fences have profound impacts on ecological systems and biodiversity, in both direct and indirect ways (Hansen et al., 2005; Kramer, 2013). Housing and infrastructure remove vegetation, which fragments remaining habitat (Hansen et al., 2005). Nutrient and biogeochemical cycles change after the removal of natural vegetation and the introduction of pollutants (Kaushal, Lewisn & McCutchan, 2006; McKinney, 2006). Homeowners manage yards, pets, and bird feeders, leading to altered hydrologic systems, exotic plants, predatory domestic pets, and resource subsidies such as food and water, nesting substrates, insulation from predators and unfavorable microclimate conditions, that favor generalist species (Boarman, Patten, Camp, & Collis, 2006; Gavier-Pizarro, Radeloff, Stewart, Huebner, & Keuler, 2010; Lepczyk, Mertig, & Liu, 2004; Longcore & Rich, 2004). Housing growth leads to an expansion of transportation infrastructure and changes travel patterns, introducing additional pollutants and disturbance (McCarty & Kaza, 2015; Wilson et al., 2013). As housing densities and impervious service increase, native species tend to decrease in abundance and richness, and human-adapted and generalist species increase (Bock, Jones, & Bock, 2008; DeStefano & DeGraaf, 2003; Gude, Hansen, & Jones, 2007; McKinney, 2006). Low-density residential development is of particular concern because it extends the environmental impacts of each house over a large area, maximizing the cumulative footprint of housing development and infrastructure (Hansen et al., 2005; Leinwand, Theobald, Mitchell, & Knight, 2010), and it often occurs in proximity to public protected lands (Radeloff et al., 2010; Wade & Theobald, 2010).

To address the adverse environmental effects of dispersed housing development and the continued demand for housing in rural areas, planners and conservation managers are searching for alternative approaches to residential development that minimize impacts on biodiversity and ecosystem functioning (Hostetler, Allen, & Meurk, 2011; Miller et al., 2009). One such option is conservation development (CD), where a portion of the property is protected as open space, and housing is typically clustered together on smaller lots (Arendt, Harper, & Trust, 1996; Pejchar et al., 2007). Ideally, CDs are designed to minimize the negative disturbances of residential development by constraining the size and extent of home sites, and protecting the most ecologically important areas in communal "open space" (Pejchar et al., 2007). These subdivisions are often developed under special ordinances that provide guidelines for their design, configuration, and management (Allen, Moorman, Peterson, Hess, & Moore, 2012; Reed, Hilty, & Theobald, 2014). Most commonly, ordinances specify the proportion of the parcel that must be protected as open space, often more than 50% of the site area (Reed et al., 2014). The open space portion of these subdivisions may be designed to explicitly protect biodiversity and ecosystem services (Pejchar et al., 2007), or with goals of protecting agriculture and ranch lands, cultural resources, or aesthetic values (Milder & Clark, 2011). CD open spaces may be legally protected, either owned by or under conservation easement with a public or nonprofit conservation organization, or managed by restrictive covenants (Milder & Clark, 2011).

CDs may be financially advantageous for developers, allowing them to reduce costs by clustering homes and infrastructure (McMahon, 2010), and to command a price premium for homes because people value living in proximity to open space (Bowman, Thompson, & Colletti, 2009; Hannum, Laposa, Reed, Pejcharn & Ex, 2012). For some expensive parcels of land, integrating limited housing may be the only feasible way to purchase land for conservation (Milder & Clark, 2011). CDs may confer broader social benefits such as preserving working landscapes or agriculture (Milder & Clark, 2011), providing a low-cost way for local governments and non-profits to conserve land during development (Pejchar et al., 2007), promoting environmental stewardship by homeowners (Thompson, 2004), and conferring psychological and health benefits to residents through access to open space (Fuller et al., 2007; Jackson, 2003).

Given their potential ecological, economic, and social benefits, interest in these communities has been growing. In the U.S. they are among the most commonly used land-use planning tools for conservation (study of local governments of Des Moines, Iowa; Seattle, Washington; and Research Triangle, North Carolina) (Miller et al., 2009), and across the western U.S., 31% of all counties have enacted CD ordinances (Reed et al., 2014). CDs comprise a growing proportion of residential development (McMahon & Pawlukiewicz, 2003), and have become an active area of research in the land use and conservation communities (Allen, Moorman, Peterson, Hess, & Moore, 2013; Göçmen, 2013; Hostetler & Drake, 2009; Milder & Clark, 2011; Reed et al., 2014). Globally, CDs (termed "conservation communities" or "eco-estates") have also been used to balance residential development and conservation in Canada, Latin America, Australia, and South Africa (Arendt, 2015; Ballard & Jones, 2011; Beatley & Newman, 2008; Tecklin & Sepulveda, 2014).

Advocates envision that these developments will provide ecological benefits beyond the borders of each development, contribute to land protection and the preservation of ecosystem services at the landscape level, and extend publically protected lands (Carter, 2009; Freeman & Bell, 2011; Milder, 2007). Although public lands are extensive in the western U.S., they do not contain the most productive and biodiverse lands, which remain privately held (Hansen et al., 2005). Public land holdings are much sparser in other regions of the country (Merenlender, Huntsinger, Guthey, & Fairfax, 2004), and across the U.S., public lands are increasingly bordered by housing development (Radeloff et al., 2010; Wade & Theobald, 2010). Expanding protection of private lands and maintaining connectivity across landscapes will benefit wildlife and ecosystem processes that often require large, contiguous areas of high-quality land (Fahrig, 2003; Fischer & Lindenmayer, 2007), and land conservation needs will only increase with climate change (Dawson, Jackson, House, Prentice, & Mace, 2011; Hiley, Bradbury, Holling, & Thomas, 2013).

However, despite the assumed benefits of CDs, studies are only now emerging to evaluate the extent to which these subdivisions contribute to conservation goals. Studies have documented the size of subdivisions, amount of land conserved, configuration of lots and open space (Göçmen, 2013; Milder & Clark, 2011; Milder, Lassoie, & Bedford, 2008) and their ecological performance (Göçmen, 2013; Lenth, Knight, & Gilgert, 2006; Nilon, Long, & Zipperer, 1995), with mixed results. Beyond individual CD subdivisions, it is unclear how the benefits of CDs accumulate and contribute to landscape-level conservation. These subdivisions are developed on privately owned lands, and they are established and sold in response to local and larger economic and social forces. Depending on local regulations, creating CDs may require more work from developers, extra fees, and longer approval times than conventional development (Carter, 2009), which may hinder their widespread implementation, and accordingly, the total amount of land they can protect.

To evaluate the contribution of conservation development to housing supply and protected lands at a landscape scale, we analyzed the number, size, and distribution of CDs in Colorado.

Colorado is an apt location for this study, because similar to many other areas in the western U.S., it has experienced rapid population growth, much of it driven by access to natural amenities. Despite substantial federal land holdings, there is growing concern about the impacts of low-density development, both on private land and adjacent protected lands (Wallace, Theobald, Ernst, & King, 2008). Much of the state is mountainous and high elevation areas are federally protected from development (National Forests, National Parks). Metropolitan development is concentrated in lower elevation areas along the Front Range of the Rocky Mountains, and low-density housing is extensive throughout the state, including it in proximity to protected areas (Leinwand et al., 2010; Riebsame, Gosnell, & Theobald, 1996; Wallace et al., 2008). Colorado has a long history of open space conservation, and nearly half of its counties have CD regulations (Reed et al., 2014). Determining how CDs contribute to housing and land conservation will inform their future use in land-use planning and conservation efforts here, and provide a model for other regions of the world facing rapid development of rural open space.

Our first objective was to document the number and size of CDs, to assess their contribution to housing and conservation at the county level. Previous national assessments estimated that 3% of all new residential subdivisions are CDs (McMahon & Pawlukiewicz, 2003). Milder and Clark (2011) found that 752 CDs protected more than 760,000 ha from 1968 to 2008, or approximately 4.2% of private land conservation nationwide (excluding projects with reserved home sites, or "conservation buyer" projects). By studying all CDs across a state, we expand upon past studies which have either been limited to a single county (Göçmen, 2013), or sample-based across a wider area (Milder & Clark, 2011; Milder et al., 2008). Our second objective was to determine if CDs are configured to buffer and extend protected areas. While there are no standard or common regulations on how CDs are to be designed, nearly half of Colorado counties with CD ordinances (48% of 33 counties) currently include guidelines to encourage the contiguity of open space with protected lands or open-space networks outside the development property; similar guidelines were found in 32% of CD ordinances assessed for counties across the western US (Reed et al., 2014). We first assessed if CDs are adjacent to, and thus buffer, protected areas. We then determined if CDs contribute to connectivity, quantifying how many CDs were adjacent to multiple protected areas, and how much the exterior perimeter of CDs overlapped with protected areas. CDs that are adjacent to multiple protected areas and have greater proportions of perimeter shared with protected areas are poised to contribute to connectivity and extend protected areas. Lastly, our third objective was to examine if CD location and configuration reflect broader patterns of protected and developed land, to determine if CDs are being deliberately located or arranged to contribute to connectivity. We might expect CDs to be located near protected areas, similar to other housing development (Leinwand et al., 2010; McDonald et al., 2007; Radeloff et al., 2010; Wade & Theobald, 2010), but also near towns and cities (Johnson & Stewart, 2005; Leinwand et al., 2010), as new residents are drawn by both natural and cultural amenities. Conversely, if CDs are not preferentially placed in proximity to protected areas, the configuration of CDs, or amount of border shared with protected areas, might directly follow from the amount of protected land in the county (a county with a large amount of one type of protected land would have more CD perimeter shared with that protected land type). Therefore, we examined how the amount of border shared with protected areas was related to the overall proportion of land protected by each ownership type. We conducted all analyses at the county level throughout the state because counties in the western U.S. have jurisdiction over development decisions in unincorporated areas, defined as private lands outside of incorporated cities and towns, where the environmental impacts of low-density development are often of particular concern.

2. Methods

With a working group at Colorado State University, we compiled a spatial database of CD subdivisions (Fig. 1). First, we identified counties in Colorado with regulations that established guidelines or incentives for conservation development (i.e., cluster development, open space development, or conservation subdivision) (Reed et al., 2014) (Fig. 1). Then, working with each county's land-use planning department, we identified subdivisions that had been developed using CD ordinances, and we mapped each CD's housing lots and open space in a geographic information system (GIS) database (Fig. 2). Of the 33 counties with CD ordinances in 2010, 19 had completed at least one CD, with a total of 352 CDs in Colorado. We focused our research on the 13 counties with the majority of these subdivisions (343 CDs, 97% of those identified in Colorado; Fig. 1). Approximately 8% of the CDs in our dataset (n = 26) had spatial data that were incomplete (missing data on open space and/or lots) or inconsistent (combined area of open space and lots differed from total subdivision area by 10% or more), leaving 317 CDs with complete spatial data. We used these data on subdivision locations and configuration along with information on protected areas from the Colorado Ownership, Management, and Protection (COMaP) data set (Lavender, Fink, Linn, & Theobald, 2011), census data on housing (U.S. Census Bureau, 2011), and data on incorporated areas from Colorado Department of Transportation (2011) to examine CDs in relation to land use and protection. We performed all spatial analyses in ArcGIS (ESRI, 2014) and all statistical analyses in R (R Development Core Team, 2014) and SAS (SAS Institute Inc., 2012).

2.1. CD contributions to housing and land protection

We examined how CDs contributed to total land protected and number of housing units in the unincorporated area of each county by comparing the area of CD open spaces and CD lots with data on land ownership and protection from COMaP. Protected lands are those that cannot be developed for housing. These lands can be owned by governments, private individuals, or non-profits, or development may be restricted by conservation easements or covenants. We included five different types of protected land ownership in our analyses: federal, state, local, private/NGO, and CD open space. All remaining land is privately owned and unprotected, and may either have housing, or could be developed for housing in the future (hereafter "developable lands"). We conducted our analyses at the county level, as each county has varying patterns of land protection and development (Table 1). The COMaP database frequently did not include accurate information about CD housing and open space; for example, more than 60% of CD open space was classified as unprotected in COMaP, while some CD lots were classified as protected. Therefore, we used our CD database to adjust area of privately-protected land, total area of protected lands, and developable lands for each county in the COMaP database.

To determine the contribution of CDs to housing, we calculated the number and area of CD lots relative to total housing units in unincorporated areas of each county. As incorporated areas do not always align with the boundaries of census blocks, we considered any census block with more than 50% unincorporated area to be unincorporated. Assuming that many of the census blocks surrounding incorporated areas have higher populations and more housing units, this allowed us to make conservative estimates regarding the contributions of CDs to housing. To avoid underestimating the contributions of CD to land protection and housing in

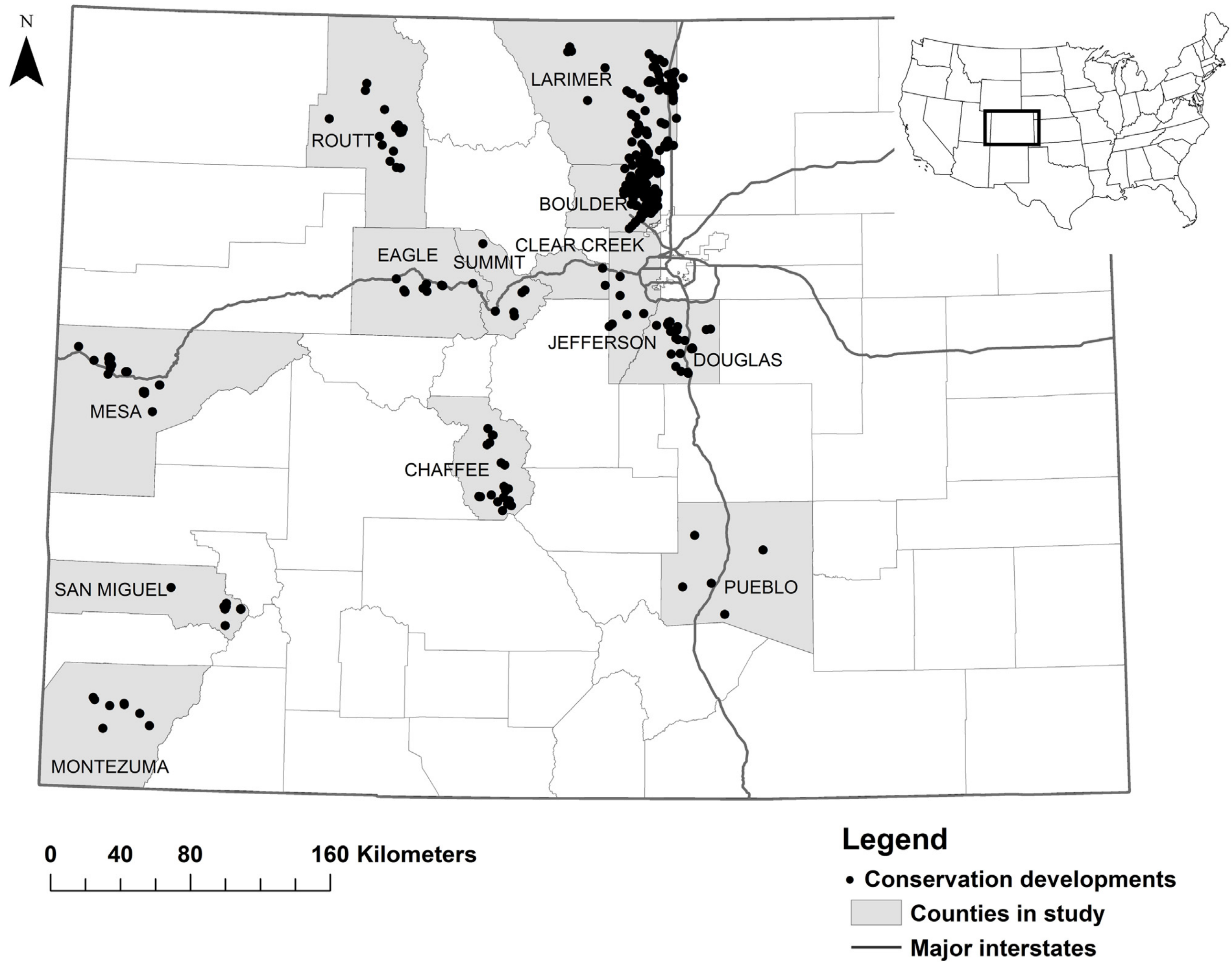

Fig. 1. Location of conservation developments in the counties included in this study in Colorado, U.S.A. (n = 343).

each county, we estimated area of open space and lots in the 26 subdivisions with missing or inconsistent spatial data, by extrapolating the mean proportions of open space and lots from the portion of the dataset with complete spatial information (n = 317). We similarly estimated the number of lots by dividing each CD's total lot area by mean lot size from the dataset with complete spatial information (n = 317).

2.2. CD configuration to buffer and connect protected areas

We examined the configuration of CDs in relation to protected areas in several ways. First, we determined if each CD was adjacent to protected areas. We calculated the percentage of these subdivisions adjacent to each type of protected area (federal, state, local, private/NGO, and CD open spaces) and to all protected areas combined. We then calculated the number of CDs adjacent to more than

Table 1
Proportion of conservation development (CD) perimeter overlapping with different protected area types in 13 Colorado counties (n = 317). Within each protected area type, counties sharing the same letter are not significantly different at p = 0.05 level.

County	No. of CDs	All protected areas (PAs)		Federal		State		Local		Private/NGO		CD open space	
Boulder	138	37.3	A	0.3	A	0.0	A	15.2	A	6.8	A	14.9	A
Chaffee.	12	17.3	ABCD	7.1	BC	0.9	AB	0.0	B	5.1	AB	4.2	AB
Clear Creek	2	19.0	ABCD	0.0	ABC	0.0	AB	7.4	AB	11.6	AB	0.0	AB
Douglas	16	12.3	BCD	1.4	AC	3.6	AB	5.2	AB	2.1	B	0.1	B
Eagle	4	17.0	ABCD	12.7	BC	0.0	AB	4.3	AB	0.0	AB	0.0	AB
Jefferson	6	3.0	BCD	0.0	ABC	3.0	AB	0.0	AB	0.0	AB	0.0	AB
Larimer	82	15.8	BCD	1.8	AC	2.0	AB	2.3	B	2.7	B	7.1	B
Mesa	17	6.5	C	3.7	AC	0.3	AB	0.0	B	0.0	B	2.5	AB
Montezuma	8	0.5	CD	0.5	ABC	0.0	AB	0.0	AB	0.0	AB	0.0	AB
Pueblo	5	13.5	ABCD	2.9	ABC	6.7	AB	0.0	AB	3.8	AB	0.0	AB
Routt	16	27.9	ABD	6.7	BC	5.4	B	2.8	AB	7.1	AB	5.9	AB
San Miguel	6	34.9	ABD	30.0	B	1.9	AB	0.0	AB	3.0	AB	0.0	AB
Summit	5	40.1	AB	36.4	B	0.0	AB	3.6	AB	0.1	AB	0.0	AB
mean:		25.3		2.8		1.2		7.8		4.5		8.9	

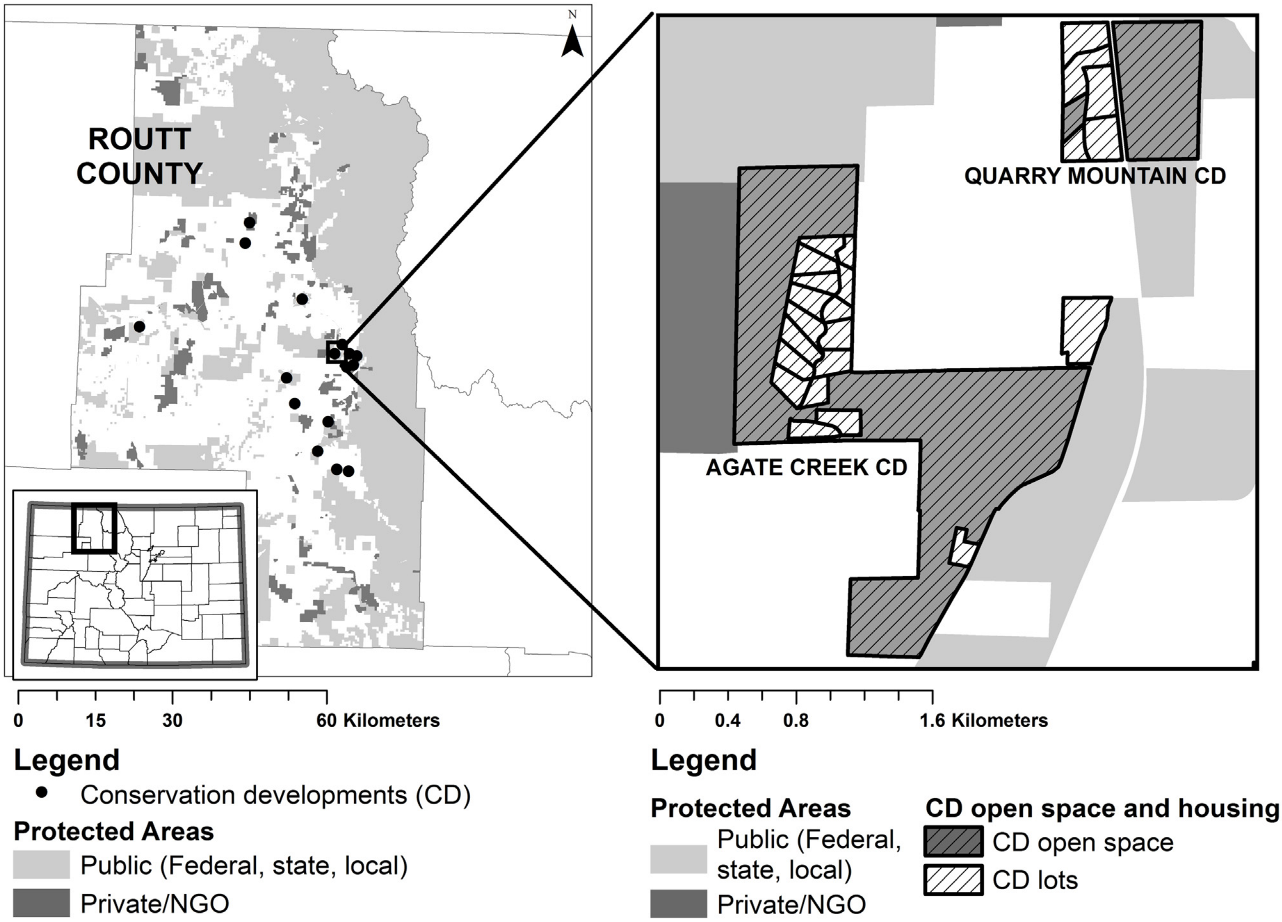

Fig. 2. Location of conservation developments (CD) relative to public (federal, state, local ownership) and private protected areas in Routt County, with inset showing CD lots and CD open space perimeter relative to protected areas for two CDs. White background areas on the map are non-protected, privately owned lands.

one type of protected area (for example, adjacent to both local and private protected lands). Tallies of ownership types do not reflect the number of individual owners within types; thus, a CD adjacent to two privately-protected properties would be counted as adjacent to one ownership type, although it could share perimeter with two different owners.

Knowing that a CD is merely adjacent to protected areas, however, does not supply any information about how much of its border overlaps with protected areas, which will influence connectivity with protected lands. For example, both CDs shown in Fig. 2 are adjacent to protected areas, but different proportions of their perimeters are adjacent to protected areas. Thus, we quantified the length of CD perimeters overlapping with protected areas (buffering 25 m out from each perimeter, to account for rights of way and complex geometries) and then calculated the proportion of the buffer perimeter length that fell within protected areas. Following Wallace et al. (2008), we classified CDs by the proportion of perimeter shared with protected areas: Touching (≤1%), Low (1–25%), Moderate (25–50%), High (50–75%), and Infill (≥75%), and we calculated how much each classification type contributed to total length of perimeter shared with protected areas. We then investigated how CD perimeter overlap varied by county and by protected area type (all protected areas combined, federal, state, local, private/NGO, or open space from another CD) using a beta regression, with CD subdivision as a repeated measure. In order to model the proportion of perimeter shared with protected areas we transformed our data, adding or subtracting 0.01 from values of 0 or 1, respectively, to use the logit link required by beta regression (Smithson & Verkuilen, 2006). We used a post-hoc Tukey's test to determine if counties were significantly different from each other for each protected area type. We restricted our analyses only to the exterior perimeter of CDs because patterns of protected area overlap were similar for the perimeters of open space areas. All analyses of subdivision configuration included only those developments for which we had complete spatial data (n = 317).

2.3. CD location on the landscape relative to natural and cultural amenities

We examined the distribution of CDs in relation to protected areas and incorporated places to test if these subdivisions were preferentially clustered near natural amenities (protected areas) and/or cultural amenities and services (incorporated places). To measure each CD's distance to amenities we calculated the Euclidean distance from the center (hereafter, centroid) of the subdivision's housing lots to the nearest protected area and nearest incorporated place. We calculated distance to the nearest protected area for all protected areas combined, and for each type of protected area (federal, state, local, private/NGO, and CD open space) individually. We used protected and incorporated areas statewide, to avoid boundary effects at county borders. We compared the proximity of CDs to protected areas and incorporated areas to the proximity of other developable points to these natural and cultural amenities. To represent developable lands, we chose 1000 random points (hereafter, developable points), sampled with replacement, from each county's developable land in unincorporated areas. We compared mean distances to protected areas and incorporated places in each county from centroids and developable points using a modified

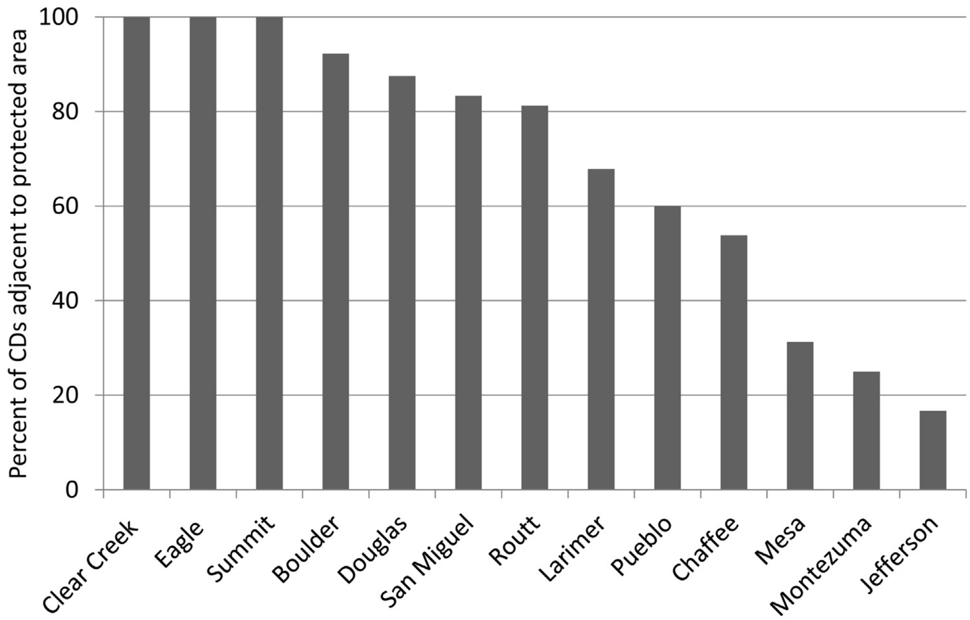

Fig. 3. Proportion of conservation developments adjacent to protected areas in thirteen Colorado counties (see also Supplemental Table 2).

t-test of spatial association, an appropriate test given the spatial autocorrelation in land ownership data (Clifford, Richardson, & Hémon, 1989). Counties vary substantially in their relative amounts of protected lands and number of CDs (Table 1), so we ran these analyses individually for each county with adequate sample size (≥10 CDs) (Boulder, Chaffee, Douglas, Larimer, Mesa, and Routt counties; a total of 289 CDs).

We next examined how the configuration of CDs, or proportion of perimeter overlapping with protected areas, related to the proportion of each protected land type in a county. We used a regression analysis to examine if each county's proportion of protected area land (predictor) was correlated with each county's average proportion of CD perimeter overlapping with that type of protected area (response). Each regression had 12 data points (counties), which included all CDs for which we had complete spatial data (n = 317). We ran a similar regression analysis, but with proportion of CD subdivisions adjacent to protected areas as the response (instead of proportion of perimeter overlapping). Results between the two regression analyses were similar, so we only report the results of the regression with proportion of perimeter shared.

3. Results

3.1. CD contributions to housing and land protection

In total, 343 CD subdivisions in 13 counties had 5245 lots (7655 ha) and 19,744 ha of protected land in open space. Lots in CD subdivisions comprised a mean of 4% ± 1.4 standard error of the mean (SEM) of housing in the unincorporated area of each county (range: 0.04–19%) (Supplemental Table 1). Although counties had an average of 66% of land protected, relatively little of that was in privately owned, protected lands, which include CD open space (Supplemental Table 1). Open space within CD subdivisions made a small contribution (<1.0%) to the protected land in unincorporated areas of all counties except Boulder (3.5%) and Douglas (3.7%) counties. However, CD open space comprised a mean of 11.2% ± 3.2 SEM (range: 1–40%) of privately protected land area. Counties with a large number of these subdivisions (e.g., Boulder and Larimer counties) had higher contributions of CD open space to privately-protected lands (30% and 15% respectively), but even in counties with relatively few of these subdivisions (e.g., Chaffee, Douglas, and Summit), CD open space contributed a substantial proportion (>10%) of private protected land (Supplemental Table 1).

3.2. CD configuration to buffer and connect protected areas

The majority (76.3%) of the 317 CDs in the 13 counties examined were adjacent to some type of protected area. Proportions varied by county, but for 10 of the 13 counties, more than half of CDs were adjacent to protected areas (Fig. 3). The most common type of adjacent protected area was the open space of another CD subdivision (41.0%). CDs were also frequently adjacent to local (33.8%) and private/NGO protected lands (24.6%) and less frequently adjacent to federal (10.4%) and state lands (7.6%) (Supplemental Table 2). Adjacency to different types of protected areas varied across counties. For example, overall, relatively few CDs were adjacent to federal lands, but percentages were 80% or more in Summit and San Miguel counties (Supplemental Table 2). CDs in Boulder, Larimer, and Routt counties were more frequently adjacent to the open space of other CD subdivisions (≥25%), while Clear Creek, Douglas, Pueblo, and Routt counties had the highest proportion of CDs adjacent to privately-protected lands (≥35%) (Supplemental Table 2). CDs were most commonly adjacent to only one type of protected area (135 CDs, or 42.6% of 317 CDs). However, 33.7% of these subdivisions connected multiple types of protected areas: 85 CDs (26.8%) were adjacent to two different protected area ownership types, 21 CDs (6.6%) to three ownership types, and one CD (0.3%) to four ownership types.

One-quarter (25.3%) of CD perimeters (n = 317) overlapped with protected areas. For those CDs that did share perimeter with protected areas (n = 242), the majority fell into the Low (1–25%) or Moderate (25–50%) classes of perimeter shared, with 100 and 81 CDs in each category across the state (Supplemental Table 3). These subdivisions were rarely embedded within or surrounded by protected areas: High (50–75%) and Infill (≥75%) classes of perimeter shared had 36 and 18 CDs in each category, respectively. Nearly all infill CDs were located in Boulder County (n = 14) (Supplemental Table 3). Only a few subdivisions (n = 7) fell in the lowest class of perimeter overlap, Touching (≤1%). The Moderate and High classes

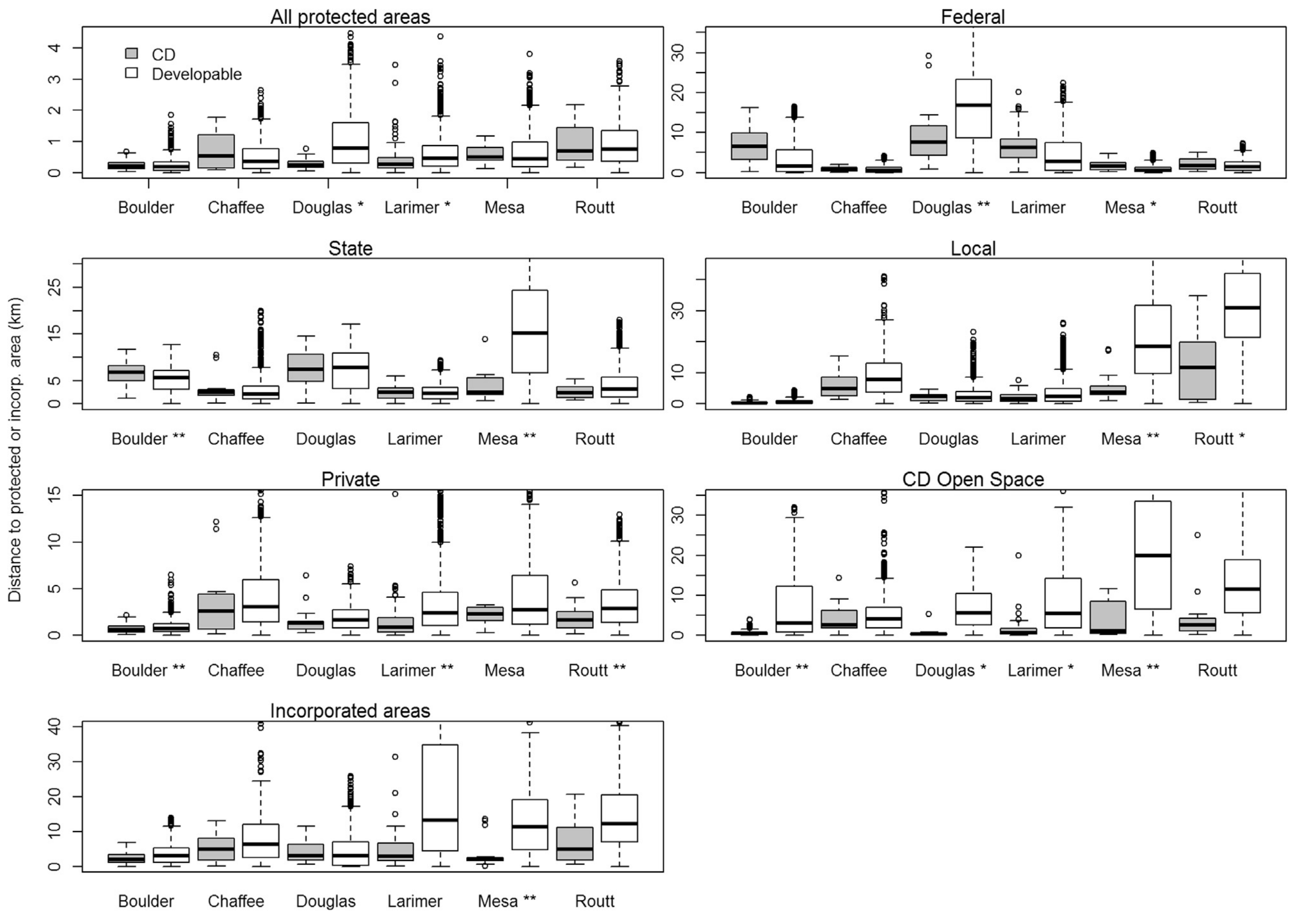

Fig. 4. Boxplots of distances from conservation development (CD) centroids and random points within unincorporated, developable lands to protected areas (all protected areas combined, federal, state, local, private/NGO, and CD open space). Statistically significant differences from modified *t*-tests of spatial association indicated (* = 0.10, ** = 0.05).

contributed to the greatest total length of perimeter shared with protected areas (35% and 33% of total km that was shared with protected areas fell into these classes, respectively), and the remaining perimeters shared with protected areas were evenly divided in the Low and Infill classes (16% each) (Supplemental Table 3). The proportion of CD perimeters overlapping with protected areas varied significantly by county ($F = 3.05$, $p = 0.0003$), protected area type ($F = 27.86$, $p < 0.0001$), and with the interaction between county and protected area type ($F = 5.46$, $p < 0.0001$). Percent of CD perimeter shared with different protected area types were consistently low except for a few counties (Table 1): CDs in Boulder had high proportions of their perimeters that overlapped with local protected areas (15.2%) and CD open space (14.9%), while CDs in San Miguel and Summit counties had high proportions that overlapped with federal lands (30.0% and 36.4%, respectively).

3.3. *CD location on the landscape relative to natural and cultural amenities*

In the six counties where we examined distance from CD housing to amenities, CDs (n = 289) were located a mean of 383 m ± 25 SEM from the nearest protected area (range = 0–3453 m), closer than developable points (mean = 672 m ± 9 SEM, range = 0–4471 m). In Douglas and Larimer counties, these subdivisions were 3.7 and 1.4 times closer to protected areas than developable points, respectively ($p = 0.002$; $p = 0.04$). These patterns were driven primarily by the proximity of these subdivisions to the open space of other CDs: in Douglas County, these subdivisions were 10.5 times closer than developable points to the open space of other CDs ($p = 0.003$), and 6.1 times closer in Larimer County ($p = 0.03$) (Fig. 4). In Routt County, CDs were 2.8 times closer to local protected areas than developable points ($p = 0.03$), and in Mesa County, CDs were located 1.8 times farther from federal lands than developable points ($p = 0.03$). Across the six counties, CDs were located a mean of 3847 m ± 312 SEM from the nearest incorporated place (range = 0-49,507 m), closer than developable points (mean = 11,127 m ± 170 SEM, range = 0–76,470 m), but differences were not statistically significant for any of the counties (Fig. 4)

The proportion of subdivision perimeter overlapping with protected area was not related to the overall proportion of protected land in the county, for federal, private/NGO, and all protected areas combined (all protected areas $F = 0.88$, $R^2 = -0.01$, $p = 0.37$; federal $F = 2.34$, $R^2 = 0.10$, $p = 0.15$; private/NGO $F = 0.06$, $R^2 = -0.09$, $p = 0.81$) (Table 1, Supplemental Table 1). However, perimeter overlap was positively related to the relative amount of state protected land ($F = 18.2$, $R^2 = 0.59$, $p = 0.001$), local protected areas ($F = 9.71$, $R^2 = 0.42$, $p = 0.01$), and CD open space in the county ($F = 9.52$, $R^2 = 0.42$, $p = 0.01$), although for both local protected areas and CD open space, these relationships were driven primarily by the large amount of local protected areas and CD open space in Boulder County (Supplemental Table 1) (regressions were no longer significant when Boulder was excluded).

4. Discussion and conclusions

Expanding residential development and rising per capita land consumption is a conservation challenge in the U.S. (Gude et al., 2007; Radeloff et al., 2005; Wade & Theobald, 2010) and globally (Bradbury et al., 2014). Conservation developments have emerged as an alternative approach to traditional dispersed development that may not only minimize the footprint of development and protect land, but extend protected areas and maintain functional ecosystems across landscapes (Arendt, 2015; Carter, 2009; Milder, 2007). By assessing the number, size, location, and configuration of CDs in Colorado in relation to protected areas and developable lands we found evidence suggesting that CDs are poised to contribute to landscape-level conservation, as well as evidence that they are currently limited in size and location on the landscape. Although these subdivisions conserve substantial private lands, and are often near protected areas, they make a small contribution to housing and protected lands overall, without clear evidence of deliberate placement and configuration on the landscape in relation to existing protected areas.

In Colorado, CDs generally comprise a small part of total protected lands and do not yet make up a large proportion of all homes or extend across a large area of the developable portion of counties, with a few notable exceptions (e.g., lots in San Miguel County are 19% of current housing stock). Our finding that these lots comprise a mean of 4% of housing within Colorado is consistent with the results of previous studies, which estimated that 3% of all new residential subdivisions nationally are CDs (McMahon & Pawlukiewicz, 2003). It is unclear how much these subdivisions will expand and why they are more common in some locations than others. Boulder County, with the largest number of CDs in the state (n = 143, with 4% of county's housing), now has limited land of sufficient size to be developed in CDs (Boulder County, n.d). Although still a small portion of total housing in each county, Boulder and Larimer counties did have by far the greatest numbers of CDs (67% of all we found in the state). Conservation developments may be more numerous in these counties because they have larger populations, active land use planning, and long histories of open space conservation (Lenth et al., 2006; Wallace et al., 2008); previous studies found the adoption of CDs regulations was more common in populated areas that experience more development pressure and have greater capacity in planning departments, in Massachusetts, North Carolina, and western U.S. states (Allen et al., 2013; Hawkins, 2014; Reed et al., 2014). However, Douglas and Jefferson counties are also situated along the Front Range, with long histories of open space conservation, but had lower numbers of CDs, suggesting there may be other factors related to the local economy, real estate markets, and planning regulations that influence the implementation of these subdivisions.

Similarly, the factors that influence CD placement and configuration in relation to protected areas remain unclear. Although protected areas are extensive in Colorado, we found the proximity of CDs to protected areas, the amount of perimeter shared with protected areas, and percent adjacent to protected areas did not consistently relate to the distribution or amount of protected areas (with the exception of State lands, which account for a relatively small land area and have little interface with CDs). We did find evidence for CDs forming clusters: in Larimer and Boulder counties, a respective 62% and 43% of these subdivisions were adjacent to other CDs' open spaces, and in Douglas and Larimer counties CDs were significantly closer to other CDs. Our findings about CD proximity to protected areas and incorporated areas may reflect our limited ability to include comparable subdivisions in this analysis. The developable points that we compared to CDs were selected from lands that were privately owned, regardless of whether they were developed, as we lack detailed information on the timing and location of comparable conventional developments in our study area. Similarly sized CDs and conventional developments, built at the same time, would provide an improved comparison of the spatial distribution of these two methods of residential development. Studies could also account for variation in cultural and natural amenities offered by towns and protected areas, as the relative amenities offered by protected areas vary with land management (e.g., Ham, Champ, Loomis, & Reich, 2012).

Despite these remaining questions, the amount of private land protected in CD open space and the proximity of CDs to protected areas, including those of different ownership, suggest that CDs are poised to contribute to conservation at the landscape scale. In the western U.S., federal land holdings protect predominantly high-elevation areas, leaving lower-elevation, ecologically valuable private lands a priority for protection (Hansen et al., 2005). Across all 13 counties, CDs make up an average of 11% of privately-protected lands. Of the sizable private protected lands in Boulder, Larimer, and Douglas counties (14,520–26,567 km^2), 13%–29% are protected through this mechanism. Our values of CD contribution to privately-protected land are substantially higher than Milder and Clark's (2011) estimate that these subdivisions made up approximately 4.2% of private land conservation (excluding projects with reserved home sites, or "conservation buyer" projects). Because the Colorado land protection database we used relies upon voluntary reporting from local organizations to document private protected lands (Lavender et al., 2011), our estimates may be high if private protected land is substantially underreported, as we found for private land protected through CDs.

Statewide, conservation developments were a mean of only 383 m from the nearest protected area. The vast majority were adjacent to protected areas (76.3%), most frequently to other CDs (41%), with over one-third of the CDs adjacent to more than one type of protected area. The proximity to other protected areas is explicitly encouraged by ordinances in nearly half of Colorado's counties that encourage the contiguity of open space with protected lands or open-space networks outside the development property (Reed et al., 2014). Our finding that CDs are frequently adjacent to protected areas is not wholly unexpected: proximity to protected areas has been related to higher development rates (McDonald et al., 2007; Radeloff et al., 2010; Wade & Theobald 2010), as homeowners take advantage of recreational and scenic amenities available near protected lands, and private lands and development are commonly adjacent to public lands in forested areas in Colorado (Leinwand et al., 2010). However, our findings on the high proportion of CDs adjacent to protected areas exceeds previous estimates from one county in Wisconsin, where approximately 10% of CD open spaces were adjacent to neighboring CD's open spaces and 30% were adjacent to state-designated conservation priority areas (Göçmen, 2013). Nationally, 15–30% of individual CDs had buffering protected areas as an explicit objective (objectives determined from interviews and document analysis in a national survey of CDs) (Milder & Clark, 2011).

4.1. Implications for landscape-level conservation and land use planning

While the location of CDs in relation to existing protected areas and the sizes of their open spaces in Colorado suggests that they may be poised to contribute to landscape-level conservation (Carter, 2009; Freeman & Bell, 2011; Milder, 2007), their functional connectivity and ecological benefits remain to be substantiated. The footprint of homes may be limited in CDs, but the well-documented negative impacts of housing on ecological systems (e.g., loss and fragmentation of wildlife habitat, introduction of invasive and non-native species) (Hansen & DeFries, 2007; Hansen et al., 2005) remain even when homes are clustered (e.g., Nilon et al., 1995). Conservation benefits will depend on a multitude of factors, including the location, design, and management of both open space and housing (Hostetler & Drake, 2009; Reed et al., 2014), and the wildlife species and ecosystem processes to be conserved (Goad, Pejchar, Reed, & Knight, 2014; Hostetler & Drake, 2009). Across the western U.S., CD ordinances rarely require ecological analyses to inform open space siting (13% of ordinances), and only 28% require a management plan for protected lands (Reed et al., 2014). A study of CD open spaces in Boulder County confirmed that management is critical: open spaces were not actively managed for conservation, and performed similarly to conventional development, with higher densities of non-native and human-commensal species, and loss of native and human-sensitive species (Lenth et al., 2006).

The high number of CDs adjacent to private and locally-protected lands in our study, including those adjacent to more than one protected area type, suggests that coordinating management between CDs and adjacent protected areas will be important. Each CD open space may be managed by a different organization, from a homeowner's association to local land trust, which will have different priorities, financial resources, and management styles. In our study, although more than three-quarters of all CDs were adjacent to protected areas, they were rarely embedded within or surrounded by protected areas, sharing an average of 26.1% of their perimeter with protected areas. Lastly, it is unclear how the establishment of CDs relates to the requirements of CD ordinances and patterns of land use and protection. Achieving conservation objectives will require better understanding these questions about CD configuration and placement, and examining how CD development and open space can be purposefully placed in relation to existing housing and protected areas.

However, the amount of land conserved by CDs and their current placement near protected areas suggests that local governments could work to systematically target future locations for CDs, to enhance their potential conservation benefits. Systematic placement of CDs for ecological benefits requires landscape-level information about conservation priority areas and open space, in order to designate or encourage CD establishment in desired locations (Arendt, 2015; Natural Lands Trust, 2009). In the western U.S., many high-elevation forested areas are permanently protected in federal ownership, leaving adjacent forests and lower-elevation areas (originally grasslands, often now used for ranching or agriculture) vulnerable to conversion to housing. Information about the quality, integrity, and ecological significance of different land holdings, protected and unprotected, will be valuable to regional land use planning and conservation efforts, in Colorado and elsewhere. For example, the state of Maine's wildlife agency runs a collaborative program, "Beginning with Habitat," to supply maps and data about wildlife habitat and conservation priorities, at the township and regional level, for local governments, land trusts, and conservation organizations to use proactively. These data have directly informed the location and design of conservation developments (Maine Department of Inland Fisheries & Wildlife, 2012). Similarly, the Southeastern Wisconsin Regional Planning Commission (SEWRPC) has delineated environmental priority areas over six counties, and strongly recommends that local governments use conservation development for any housing development allowed in these areas (SEWRPC, 2006). Open space areas within subdivisions are considered permanently preserved, and are mapped for multi-jurisdictional planning documents as a specific type of conserved land (SEWRPC, 2000). Considering housing development and open space acquisition at a landscape level can also contribute to other land use planning goals, such as reducing wildfire risk to homes (e.g., Butsic, Syphard, Keeley, & Bar-Massada, 2017).

Although our research focused on one state in the western U.S., with a long history of private land conservation and extensive protected areas, we expect the fundamental research questions we raise about the connectivity and performance of CDs will be highly relevant in other locations, although the ecosystem, scale of development, and level of protected open space may be different (Milder & Clark, 2011; Milder et al., 2008). Documenting the landscape-level contributions of CD to land use, as we did in this study, required a substantial effort to collect and correct spatial data on CDs from many local governments. In the U.S., a consistent effort to document and monitor these subdivisions over time, similar to or as an extension of the national conservation easements database (Foster, 2012), would greatly facilitate future evaluation of the use and conservation outcomes of CDs. A better understanding of where these subdivisions have developed, and their association with land use and the protected area estate, will increase the ecological and socioeconomic benefits of future conservation development. The specific amounts and distributions of private and protected land in Colorado may be typical of the western U.S., but the purposeful integration of housing development and land conservation across landscapes is globally relevant and could be beneficial in the many places undergoing rapid land-use change.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landurbplan.2016.09.015.

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