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

Authors: Miranda H. MOCKRIN, Human Dimensions Program, Rocky Mountain Research Station, USDA Forest Service, Fort Collins, CO. Mailing address: 5523 Research Park Drive Suite 350, Baltimore, MD 21228. Phone: 970-658-0484. Email: mhmockrin@fs.fed.us

Sarah E. REED, North America Program, Wildlife Conservation Society; Department of Fish, Wildlife and Conservation Biology, Colorado State University, Fort Collins, CO.
Email: sreed@wcs.org

Liba PEJCHAR, Department of Fish, Wildlife and Conservation Biology, Colorado State University Fort Collins, CO. Email: Liba.Pejchar@colostate.edu

Jessica SALO, Department of Geography and GIS, University of Northern Colorado, Greeley, CO. Email: jessica.salo@unco.edu

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.

Keywords: Conservation subdivision, residential development, open space, private protected areas, landscape connectivity, land use planning, subdivision design

1. Introduction

Globally, housing development and residential land consumption per person is rising with industrialization (Bradbury, Peterson and Liu, 2014), with public protected areas often insufficient to conserve biodiversity and ecosystem functioning in the face of this private land conversion (Kamal, Grodzińska-Jurczak and 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/km²) (Brown, Johnson, Loveland and Theobald, 2005; Radeloff, Hammer, Stewart, Fried, Holcomb and McKeefry, 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 mobility with retirement (Gosnell and 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 and 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, Knight, Marzluff, Powell, Brown, Gude and Jones, 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, Lewis and 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 and Collis, 2006; Gavier-Pizarro, Radeloff, Stewart,

25 Huebner and Keuler, 2010; Lepczyk, Mertig and Liu, 2004; Longcore and Rich, 2004). Housing growth leads to an
26 expansion of transportation infrastructure and changes travel patterns, introducing additional pollutants and
27 disturbance (McCarty and Kaza, 2015; Wilson, Spinney, Millward, Scott, Hayden and Tyedmers, 2013). As
28 housing densities and impervious service increase, native species tend to decrease in abundance and richness,
29 and human-adapted and generalist species increase (Bock, Jones and Bock, 2008; DeStefano and DeGraaf, 2003;
30 Gude, Hansen and Jones, 2007; McKinney, 2006). Low-density residential development is of particular concern
31 because it extends the environmental impacts of each house over a large area, maximizing the cumulative
32 footprint of housing development and infrastructure (Hansen et al., 2005; Leinwand, Theobald, Mitchell and
33 Knight, 2010), and it often occurs in proximity to public protected lands (Radeloff, Stewart, Hawbaker, Gimmi,
34 Pidgeon, Flather, Hammer and Helmers, 2010; Wade and Theobald, 2010).

35 To address the adverse environmental effects of dispersed housing development and the continued
36 demand for housing in rural areas, planners and conservation managers are searching for alternative
37 approaches to residential development that minimize impacts on biodiversity and ecosystem functioning
38 (Hostetler, Allen and Meurk, 2011; Miller, Groom, Hess, Steelman, Stokes, Thompson, Bowman, Fricke, King and
39 Marquardt, 2009). One such option is conservation development (CD), where a portion of the property is
40 protected as open space, and housing is typically clustered together on smaller lots (Arendt, Harper and Trust,
41 1996; Pejchar et al., 2007). Ideally, CDs are designed to minimize the negative disturbances of residential
42 development by constraining the size and extent of home sites, and protecting the most ecologically important
43 areas in communal “open space” (Pejchar et al., 2007). These subdivisions are often developed under special
44 ordinances that provide guidelines for their design, configuration, and management (Allen, Moorman, Peterson,
45 Hess and Moore, 2012; Reed, Hilty and Theobald, 2014). Most commonly, ordinances specify the proportion of
46 the parcel that must be protected as open space, often more than 50% of the site area (Reed et al., 2014). The
47 open space portion of these subdivisions may be designed to explicitly protect biodiversity and ecosystem
48 services (Pejchar et al., 2007), or with goals of protecting agriculture and ranch lands, cultural resources, or

49 aesthetic values (Milder and Clark, 2011). CD open spaces may be legally protected, either owned by or under
50 conservation easement with a public or nonprofit conservation organization, or managed by restrictive
51 covenants (Milder and Clark, 2011).

52 CDs may be financially advantageous for developers, allowing them to reduce costs by clustering homes
53 and infrastructure (McMahon, 2010), and to command a price premium for homes because people value living
54 in proximity to open space (Bowman, Thompson and Colletti, 2009; Hannum, Laposa, Reed, Pejchar and Ex,
55 2012). For some expensive parcels of land, integrating limited housing may be the only feasible way to purchase
56 land for conservation (Milder and Clark, 2011). CDs may confer broader social benefits such as preserving
57 working landscapes or agriculture (Milder and Clark, 2011), providing a low-cost way for local governments and
58 non-profits to conserve land during development (Pejchar et al., 2007), promoting environmental stewardship
59 by homeowners (Thompson, 2004), and conferring psychological and health benefits to residents through access
60 to open space (Fuller, Irvine, Devine-Wright, Warren and Gaston, 2007; Jackson, 2003).

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

71 Advocates envision that these developments will provide ecological benefits beyond the borders of each
72 development, contribute to land protection and the preservation of ecosystem services at the landscape level,

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

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

92 To evaluate the contribution of conservation development to housing supply and protected lands at a
93 landscape scale, we analyzed the number, size, and distribution of CDs in Colorado. Colorado is an apt location
94 for this study, because similar to many other areas in the western U.S., it has experienced rapid population
95 growth, much of it driven by access to natural amenities. Despite substantial federal land holdings, there is
96 growing concern about the impacts of low-density development, both on private land and adjacent protected

97 lands (Wallace, Theobald, Ernst and King, 2008). Much of the state is mountainous and high elevation areas are
98 federally protected from development (National Forests, National Parks). Metropolitan development is
99 concentrated in lower elevation areas along the Front Range of the Rocky Mountains, and low-density housing is
100 extensive throughout the state, including it in proximity to protected areas (Leinwand et al., 2010; Riebsame,
101 Gosnell and Theobald, 1996; Wallace et al., 2008). Colorado has a long history of open space conservation, and
102 nearly half of its counties have CD regulations (Reed et al., 2014). Determining how CDs contribute to housing
103 and land conservation will inform their future use in land-use planning and conservation efforts here, and
104 provide a model for other regions of the world facing rapid development of rural open space.

105 Our first objective was to document the number and size of CDs, to assess their contribution to housing
106 and conservation at the county level. Previous national assessments estimated that 3% of all new residential
107 subdivisions are CDs (McMahon and Pawlukiewicz, 2003). Milder and Clark (2011) found that 752 CDs protected
108 more than 760,000 ha from 1968-2008, or approximately 4.2% of private land conservation nationwide
109 (excluding projects with reserved home sites, or “conservation buyer” projects). By studying all CDs across a
110 state, we expand upon past studies which have either been limited to a single county (Göçmen, 2013), or
111 sample-based across a wider area (Milder and Clark, 2011; Milder et al., 2008). Our second objective was to
112 determine if CDs are configured to buffer and extend protected areas. While there are no standard or common
113 regulations on how CDs are to be designed, nearly half of Colorado counties with CD ordinances (48% of 33
114 counties) currently include guidelines to encourage the contiguity of open space with protected lands or open-
115 space networks outside the development property; similar guidelines were found in 32% of CD ordinances
116 assessed for counties across the western US (Reed et al., 2014). We first assessed if CDs are adjacent to, and
117 thus buffer, protected areas. We then determined if CDs contribute to connectivity, quantifying how many CDs
118 were adjacent to multiple protected areas, and how much the exterior perimeter of CDs overlapped with
119 protected areas. CDs that are adjacent to multiple protected areas and have greater proportions of perimeter
120 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, Yuan Farrell, Fievet, Moeller, Kareiva, Foster, Gragson, Kinzig, Kuby and Redman, 2007; Radeloff et al., 2010; Wade and Theobald, 2010), but also near towns and cities (Johnson and 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 [institution removed for double-blind peer review], we compiled a spatial database of CD subdivisions (Figure 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) [citation removed for peer review] (Figure 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 (Figure 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

145 those identified in Colorado; Figure 1). Approximately 8% of the CDs in our dataset (n=26) had spatial data that
146 were incomplete (missing data on open space and/or lots) or inconsistent (combined area of open space and
147 lots differed from total subdivision area by 10% or more), leaving 317 CDs with complete spatial data. We used
148 these data on subdivision locations and configuration along with information on protected areas from the
149 Colorado Ownership, Management, and Protection (COMaP) data set (Lavender, 2011), census data on housing
150 (U.S. Census Bureau, 2011), and data on incorporated areas from Colorado Department of Transportation (2011)
151 to examine CDs in relation to land use and protection. We performed all spatial analyses in ArcGIS (ESRI 2014)
152 and all statistical analyses in R (R Development Core Team 2014) and SAS (SAS Institute Inc., 2012).

153

154 2.1 CD contributions to housing and land protection

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

167 To determine the contribution of CDs to housing, we calculated the number and area of CD lots relative
168 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 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 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 Figure 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:

193 Touching ($\leq 1\%$), Low (1-25%), Moderate (25-50%), High (50-75%), and Infill ($\geq 75\%$), and we calculated how much
194 each classification type contributed to total length of perimeter shared with protected areas. We then
195 investigated how CD perimeter overlap varied by county and by protected area type (all protected areas
196 combined, federal, state, local, private/NGO, or open space from another CD) using a beta regression, with CD
197 subdivision as a repeated measure. In order to model the proportion of perimeter shared with protected areas
198 we transformed our data, adding or subtracting 0.01 from values of 0 or 1, respectively, to use the logit link
199 required by beta regression (Smithson and Verkuilen, 2006). We used a post-hoc Tukey's test to determine if
200 counties were significantly different from each other for each protected area type. We restricted our analyses
201 only to the exterior perimeter of CDs because patterns of protected area overlap were similar for the perimeters
202 of open space areas. All analyses of subdivision configuration included only those developments for which we
203 had complete spatial data (n=317).

204

205 2.3 CD location on the landscape relative to natural and cultural amenities

206 We examined the distribution of CDs in relation to protected areas and incorporated places to test if these
207 subdivisions were preferentially clustered near natural amenities (protected areas) and/or cultural amenities
208 and services (incorporated places). To measure each CD's distance to amenities we calculated the Euclidean
209 distance from the center (hereafter, centroid) of the subdivision's housing lots to the nearest protected area and
210 nearest incorporated place. We calculated distance to the nearest protected area for all protected areas
211 combined, and for each type of protected area (federal, state, local, private/NGO, and CD open space)
212 individually. We used protected and incorporated areas statewide, to avoid boundary effects at county borders.
213 We compared the proximity of CDs to protected areas and incorporated areas to the proximity of other
214 developable points to these natural and cultural amenities. To represent developable lands, we chose 1,000
215 random points (hereafter, developable points), sampled with replacement, from each county's developable land
216 in unincorporated areas. We compared mean distances to protected areas and incorporated places in each

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

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

230

231 **3. Results**

232 3.1 CD contributions to housing and land protection

233 In total, 343 CD subdivisions in 13 counties had 5,245 lots (7,655 ha) and 19,744 ha of protected land in open
234 space. Lots in CD subdivisions comprised a mean of $4\% \pm 1.4$ standard error of the mean (SEM) of housing in the
235 unincorporated area of each county (range: 0.04-19%) (Supplemental Table 1). Although counties had an
236 average of 66% of land protected, relatively little of that was in privately owned, protected lands, which include
237 CD open space (Supplemental Table 1). Open space within CD subdivisions made a small contribution ($<1.0\%$) to
238 the protected land in unincorporated areas of all counties except Boulder (3.5%) and Douglas (3.7%) counties.
239 However, CD open space comprised a mean of $11.2\% \pm 3.2$ SEM (range: 1-40%) of privately protected land area.
240 Counties with a large number of these subdivisions (e.g., Boulder and Larimer counties) had higher contributions

241 of CD open space to privately-protected lands (30% and 15% respectively), but even in counties with relatively
242 few of these subdivisions (e.g., Chaffee, Douglas, and Summit), CD open space contributed a substantial
243 proportion (>10%) of private protected land (Supplemental Table 1).
244

245 3.2 CD configuration to buffer and connect protected areas

246 The majority (76.3%) of the 317 CDs in the 13 counties examined were adjacent to some type of protected area.
247 Proportions varied by county, but for 10 of the 13 counties, more than half of CDs were adjacent to protected
248 areas (Figure 3). The most common type of adjacent protected area was the open space of another CD
249 subdivision (41.0%). CDs were also frequently adjacent to local (33.8%) and private/NGO protected lands
250 (24.6%) and less frequently adjacent to federal (10.4%) and state lands (7.6%) (Supplemental Table 2). Adjacency
251 to different types of protected areas varied across counties. For example, overall, relatively few CDs were
252 adjacent to federal lands, but percentages were 80% or more in Summit and San Miguel counties (Supplemental
253 Table 2). CDs in Boulder, Larimer, and Routt counties were more frequently adjacent to the open space of other
254 CD subdivisions ($\geq 25\%$), while Clear Creek, Douglas, Pueblo, and Routt counties had the highest proportion of
255 CDs adjacent to privately-protected lands ($\geq 35\%$) (Supplemental Table 2). CDs were most commonly adjacent to
256 only one type of protected area (135 CDs, or 42.6% of 317 CDs). However, 33.7% of these subdivisions
257 connected multiple types of protected areas: 85 CDs (26.8%) were adjacent to two different protected area
258 ownership types, 21 CDs (6.6%) to three ownership types, and one CD (0.3%) to four ownership types.

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

perimeter overlap, Touching ($\leq 1\%$). The Moderate and High classes 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 ($F=27.86$, $p<.0001$), and with the interaction between county and protected area type ($F=5.46$, $p<.0001$). 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 $383 \text{ m} \pm 25 \text{ SEM}$ from the nearest protected area (range=0-3,453 m), closer than developable points (mean= $672 \text{ m} \pm 9 \text{ SEM}$, range=0-4,471 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 ($p=0.03$) (Figure 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 $3,847 \text{ m} \pm 312 \text{ SEM}$ from the nearest incorporated place (range=0-49,507 m), closer than developable points (mean= $11,127 \text{ m} \pm 170 \text{ SEM}$, range=0-76,470 m), but differences were not statistically significant for any of the counties (Figure 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 and 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

312 comprise a mean of 4% of housing within Colorado is consistent with the results of previous studies, which
313 estimated that 3% of all new residential subdivisions nationally are CDs (McMahon and Pawlukiewicz, 2003). It is
314 unclear how much these subdivisions will expand and why they are more common in some locations than
315 others. Boulder County, with the largest number of CDs in the state (n=143, with 4% of county's housing), now
316 has limited land of sufficient size to be developed in CDs (Boulder County, n.d). Although still a small portion of
317 total housing in each county, Boulder and Larimer counties did have by far the greatest numbers of CDs (67% of
318 all we found in the state). Conservation developments may be more numerous in these counties because they
319 have larger populations, active land use planning, and long histories of open space conservation (Lenth et al.,
320 2006; Wallace et al., 2008); previous studies found the adoption of CDs regulations was more common in
321 populated areas that experience more development pressure and have greater capacity in planning
322 departments, in Massachusetts, North Carolina, and western U.S. states (Allen et al., 2013; Hawkins, 2014; Reed
323 et al., 2014). However, Douglas and Jefferson counties are also situated along the Front Range, with long
324 histories of open space conservation, but had lower numbers of CDs, suggesting there may be other factors
325 related to the local economy, real estate markets, and planning regulations that influence the implementation of
326 these subdivisions.

327 Similarly, the factors that influence CD placement and configuration in relation to protected areas
328 remain unclear. Although protected areas are extensive in Colorado, we found the proximity of CDs to protected
329 areas, the amount of perimeter shared with protected areas, and percent adjacent to protected areas did not
330 consistently relate to the distribution or amount of protected areas (with the exception of State lands, which
331 account for a relatively small land area and have little interface with CDs). We did find evidence for CDs forming
332 clusters: in Larimer and Boulder counties, a respective 62% and 43% of these subdivisions were adjacent to
333 other CDs' open spaces, and in Douglas and Larimer counties CDs were significantly closer to other CDs. Our
334 findings about CD proximity to protected areas and incorporated areas may reflect our limited ability to include
335 comparable subdivisions in this analysis. The developable points that we compared to CDs were selected from

336 lands that were privately owned, regardless of whether they were developed, as we lack detailed information on
337 the timing and location of comparable conventional developments in our study area. Similarly sized CDs and
338 conventional developments, built at the same time, would provide an improved comparison of the spatial
339 distribution of these two methods of residential development. Studies could also account for variation in
340 cultural and natural amenities offered by towns and protected areas, as the relative amenities offered by
341 protected areas vary with land management (e.g., Ham, Champ, Loomis and Reich, 2012).

342 Despite these remaining questions, the amount of private land protected in CD open space and the
343 proximity of CDs to protected areas, including those of different ownership, suggest that CDs are poised to
344 contribute to conservation at the landscape scale. In the western U.S., federal land holdings protect
345 predominantly high-elevation areas, leaving lower-elevation, ecologically valuable private lands a priority for
346 protection (Hansen et al., 2005). Across all 13 counties, CDs make up an average of 11% of privately-protected
347 lands. Of the sizable private protected lands in Boulder, Larimer, and Douglas counties (14,520 to 26,567 km²),
348 13% to 29% are protected through this mechanism. Our values of CD contribution to privately-protected land
349 are substantially higher than Milder and Clark's (2011) estimate that these subdivisions made up approximately
350 4.2% of private land conservation (excluding projects with reserved home sites, or "conservation buyer"
351 projects). Because the Colorado land protection database we used relies upon voluntary reporting from local
352 organizations to document private protected lands (Lavender, 2011), our estimates may be high if private
353 protected land is substantially underreported, as we found for private land protected through CDs.

354 Statewide, conservation developments were a mean of only 383 m from the nearest protected area. The
355 vast majority were adjacent to protected areas (76.3%), most frequently to other CDs (41%), with over one-third
356 of the CDs adjacent to more than one type of protected area. The proximity to other protected areas is explicitly
357 encouraged by ordinances in nearly half of Colorado's counties that encourage the contiguity of open space with
358 protected lands or open-space networks outside the development property (Reed et al., 2014). Our finding that
359 CDs are frequently adjacent to protected areas is not wholly unexpected: proximity to protected areas has been

360 related to higher development rates (McDonald et al. 2007, Radeloff et al. 2010, Wade and Theobald 2010), as
361 homeowners take advantage of recreational and scenic amenities available near protected lands, and private
362 lands and development are commonly adjacent to public lands in forested areas in Colorado (Leinwand et al.,
363 2010). However, our findings on the high proportion of CDs adjacent to protected areas exceeds previous
364 estimates from one county in Wisconsin, where approximately 10% of CD open spaces were adjacent to
365 neighboring CD's open spaces and 30% were adjacent to state-designated conservation priority areas (Göçmen,
366 2013). Nationally, 15-30% of individual CDs had buffering protected areas as an explicit objective (objectives
367 determined from interviews and document analysis in a national survey of CDs) (Milder and Clark, 2011).

368

369 Implications for landscape-level conservation and land use planning

370 While the location of CDs in relation to existing protected areas and the sizes of their open spaces in Colorado
371 suggests that they may be poised to contribute to landscape-level conservation (Carter, 2009; Freeman and Bell,
372 2011; Milder, 2007), their functional connectivity and ecological benefits remain to be substantiated. The
373 footprint of homes may be limited in CDs, but the well-documented negative impacts of housing on ecological
374 systems (e.g., loss and fragmentation of wildlife habitat, introduction of invasive and non-native species)
375 (Hansen and DeFries, 2007; Hansen et al., 2005) remain even when homes are clustered (e.g., Nilon et al., 1995).
376 Conservation benefits will depend on a multitude of factors, including the location, design, and management of
377 both open space and housing (Hostetler and Drake, 2009; Reed et al., 2014), and the wildlife species and
378 ecosystem processes to be conserved (Goad, Pejchar, Reed and Knight, 2014; Hostetler and Drake, 2009). Across
379 the western U.S., CD ordinances rarely require ecological analyses to inform open space siting (13% of
380 ordinances), and only 28% require a management plan for protected lands (Reed et al., 2014). A study of CD
381 open spaces in Boulder County confirmed that management is critical: open spaces were not actively managed
382 for conservation, and performed similarly to conventional development, with higher densities of non-native and
383 human-commensal species, and loss of native and human-sensitive species (Lenth et al., 2006).

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

394 However, the amount of land conserved by CDs and their current placement near protected areas
395 suggests that local governments could work to systematically target future locations for CDs, to enhance their
396 potential conservation benefits. Systematic placement of CDs for ecological benefits requires landscape-level
397 information about conservation priority areas and open space, in order to designate or encourage CD
398 establishment in desired locations (Arendt, 2015; Natural Lands Trust, 2009). In the western U.S., many high-
399 elevation forested areas are permanently protected in federal ownership, leaving adjacent forests and lower-
400 elevation areas (originally grasslands, often now used for ranching or agriculture) vulnerable to conversion to
401 housing. Information about the quality, integrity, and ecological significance of different land holdings,
402 protected and unprotected, will be valuable to regional land use planning and conservation efforts, in Colorado
403 and elsewhere. For example, the state of Maine's wildlife agency runs a collaborative program, "Beginning with
404 Habitat," to supply maps and data about wildlife habitat and conservation priorities, at the township and
405 regional level, for local governments, land trusts, and conservation organizations to use proactively. These data
406 have directly informed the location and design of conservation developments (Maine Department of Inland
407 Fisheries and 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 and 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 and 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.

References

- Allen, S. C., Moorman, C. E., Peterson, M. N., Hess, G. R., Moore, S. E., 2012, Overcoming socio-economic barriers to conservation subdivisions: A case-study of four successful communities, *Landscape and Urban Planning* **106**(3):244-252.
- Allen, S. C., Moorman, C. E., Peterson, M. N., Hess, G. R., Moore, S. E., 2013, Predicting success incorporating conservation subdivisions into land use planning, *Land Use Policy* **33**, 31–35.
- Arendt, R., 2015, *Rural by Design: Planning for Town and Country* Second Edition, APA Planners Press.
- Arendt, R., Harper, H., Trust, N. L., 1996, *Conservation design for subdivisions: a practical guide to creating open space networks*, Island Press, Washington DC.
- Ballard, R., Jones, G. A., 2011, Natural neighbors: indigenous landscapes and eco-estates in Durban, South Africa, *Annals of the Association of American Geographers* **101**(1):131-148.
- Beatley, T., Newman, P., 2008, *Green urbanism down under: Learning from sustainable communities in Australia*, Island Press.
- Boarman, W., Patten, M., Camp, R., Collis, S., 2006, Ecology of a population of subsidized predators: Common ravens in the central Mojave Desert, California, *Journal of Arid Environments* **67**:248-261.
- Bock, C. E., Jones, Z. F., Bock, J. H., 2008, The oasis effect: response of birds to exurban development in a southwestern savanna, *Ecological Applications* **18**:1093-1106.
- Boulder County, n.d, Conservation Easements. <http://www.bouldercounty.org/os/openspace/pages/ces.aspx> Accessed October 6, 2015.
- Bowman, T., Thompson, J., Colletti, J., 2009, Valuation of open space and conservation features in residential subdivisions, *Journal of environmental management* **90**(1):321-330.
- Bradbury, M., Peterson, M. N., Liu, J., 2014, Longterm dynamics of household size and their environmental implications, *Population & Environment* **36**(1):73-84.
- Brown, D. G., Johnson, K. M., Loveland, T. R., Theobald, D. M., 2005, Rural land-use trends in the conterminous United States, 1950–2000, *Ecological Applications* **15**(6):1851-1863.
- Butsic, V., Syphard, A. D., Keeley, J. E., Bar-Massada, A., 2017, Can private land conservation reduce wildfire risk to homes? A case study in San Diego County, California, USA, *Landscape and Urban Planning* **157**:161-169.
- Carter, T., 2009, Developing conservation subdivisions: Ecological constraints, regulatory barriers, and market incentives, *Landscape and Urban Planning* **92**(2):117-124.
- Clifford, P., Richardson, S., Hémon, D., 1989, Assessing the significance of the correlation between two spatial processes, *Biometrics* **45**(1):123-134.
- Dawson, T. P., Jackson, S. T., House, J. I., Prentice, I. C., Mace, G. M., 2011, Beyond predictions: biodiversity conservation in a changing climate, *Science* **332**(6025):53-58.
- DeStefano, S., DeGraaf, R. M., 2003, Exploring the ecology of suburban wildlife, *Frontiers in Ecology and the Environment* **1**(2):95-101.
- ESRI (Environmental Systems Resource Institute), 2014, ArcMap 10.1 (ESRI, ed.), Redlands, California.
- Foster, K., 2012, National Conservation Easement Database (NCED), Phase III released July 2013. <http://conservationeasement.us/>.
- Freeman, R. C., Bell, K. P., 2011, Conservation versus cluster subdivisions and implications for habitat connectivity, *Landscape and Urban Planning* **101**(1):30–42.
- Fuller, R. A., Irvine, K. N., Devine-Wright, P., Warren, P. H., Gaston, K. J., 2007, Psychological benefits of greenspace increase with biodiversity, *Biological Letters* **3**(4):390-394.
- Gavier-Pizarro, G., Radeloff, V., Stewart, S., Huebner, C., Keuler, N., 2010, Housing is positively associated with invasive exotic plant species richness in New England, USA, *Ecological Applications* **20**(7):1913-1925.
- Goad, E. H., Pejchar, L., Reed, S. E., Knight, R. L., 2014, Habitat use by mammals varies along an exurban development gradient in northern Colorado, *Biological Conservation* **176**:172-182.

- Göçmen, Z. A., 2013, Barriers to successful implementation of conservation subdivision design: A closer look at land use regulations and subdivision permitting process, *Landscape and Urban Planning* **110**:123-133.
- Gosnell, H., Abrams, J., 2011, Amenity migration: diverse conceptualizations of drivers, socioeconomic dimensions, and emerging challenges, *GeoJournal* **76**(4):303-322.
- Gude, P. H., Hansen, A. J., Jones, D. A., 2007, Biodiversity consequences of alternative future land use scenarios in Greater Yellowstone, *Ecological Applications* **17**(4):1004-1018.
- Ham, C., Champ, P. A., Loomis, J. B., Reich, R. M., 2012, Accounting for heterogeneity of public lands in hedonic property models, *Land Economics* **88**(3):444-456.
- Hannum, C., Laposa, S., Reed, S. E., Pejchar, L., Ex, L., 2012, Comparative analysis of housing in conservation developments: Colorado case studies, *The Journal of Sustainable Real Estate* **4**(1):149-176.
- Hansen, A. J., DeFries, R., 2007, Ecological mechanisms linking protected areas to surrounding lands, *Ecological Applications* **17**(4):974-988.
- Hansen, A. J., Knight, R. L., Marzluff, J. M., Powell, S., Brown, K., Gude, P. H., Jones, K., 2005, Effects of exurban development on biodiversity: patterns, mechanisms, and research needs, *Ecological Applications* **15**(6):1893-1905.
- Hawkins, C. V., 2014, Landscape conservation through residential subdivision bylaws: Explanations for local adoption, *Landscape and Urban Planning* **121**:141-148.
- Hiley, J. R., Bradbury, R. B., Holling, M., Thomas, C. D., 2013, Protected areas act as establishment centres for species colonizing the UK, *Proceedings of the Royal Society of London B: Biological Sciences* **280**(1760):20122310.
- Hostetler, M., Allen, W., Meurk, C., 2011, Conserving urban biodiversity? Creating green infrastructure is only the first step, *Landscape and Urban Planning* **100**(4):369-371.
- Hostetler, M., Drake, D., 2009, Conservation subdivisions: a wildlife perspective, *Landscape and Urban Planning* **90**(3):95-101.
- Jackson, L. E., 2003, The relationship of urban design to human health and condition, *Landscape and Urban Planning* **64**(4):191-200.
- Johnson, K. M., Stewart, S. I., 2005, Recreation, amenity migration and urban proximity, in: *Amenities And Rural Development: Theory, Methods And Public Policy* (G. P. Green, S. C. Deller, D. W. Marcouiller, eds.), pp. 177-196.
- Kamal, S., Grodzińska-Jurczak, M., Brown, G., 2015, Conservation on private land: a review of global strategies with a proposed classification system, *Journal of Environmental Planning and Management* **58**(4):576-597.
- Kaushal, S. S., Lewis, W. M., McCutchan, J. H., 2006, Land use change and nitrogen enrichment of a Rocky Mountain watershed, *Ecological Applications* **16**:299-312.
- Kramer, M., 2013, Our built and Natural Environments: A technical review of the interactions among land use, transportation, and environmental quality. Environment Protection Agency, Smart Growth Program. Washington, D.C.: U.S. Government.
- Lavender, A. E., M.M. Fink, S.E. Linn, D.M. Theobald 2011, Colorado Ownership, Management, and Protection v9 Database. Colorado Natural Heritage Program and Geospatial Centroid, Colorado State University, Fort Collins, CO. (30 September).
- Leinwand, I. I., Theobald, D. M., Mitchell, J., Knight, R. L., 2010, Landscape dynamics at the public-private interface: A case study in Colorado, *Landscape and Urban Planning* **97**(3):182-193.
- Lenth, B. A., Knight, R. L., Gilgert, W. C., 2006, Conservation value of clustered housing developments, *Conservation Biology* **20**(5):1445-1456.
- Lepczyk, C. A., Mertig, A. G., Liu, J., 2004, Landowners and cat predation across rural-to-urban landscapes, *Biological Conservation* **115**(2):191-201.
- Longcore, T., Rich, C., 2004, Ecological light pollution, *Frontiers in Ecology and the Environment* **2**(4):191-198.

- Maine Department of Inland Fisheries and Wildlife, 2012, *Beginning with Habitat: Conserving Maine's natural landscape for plants, animals, and people*, Augusta, ME.
<http://www.beginningwithhabitat.org/pdf/BWHtext.pdf>.
- McCarty, J., Kaza, N., 2015, Urban form and air quality in the United States, *Landscape and Urban Planning* **139**:168-179.
- McDonald, R. I., Yuan Farrell, C., Fievet, C., Moeller, M., Kareiva, P., Foster, D., Gragson, T., Kinzig, A., Kuby, L., Redman, C., 2007, Estimating the effect of protected lands on the development and conservation of their surroundings, *Conservation Biology* **21**(6):1526-1536.
- McKinney, M. L., 2006, Urbanization as a major cause of biotic homogenization, *Biological Conservation* **127**(3):247-260.
- McMahon, E. T., 2010, *Conservation communities: Creating value with nature, open space, and agriculture*, Urban Land Institute., Washington DC.
- McMahon, E. T., Pawlukiewicz, M., 2003, *The practice of conservation development: lessons in success*, Urban Land Institute/The Conservation Fund, ULI Land Use Policy Forum Report in Partnership with The Conservation Fund.
- Merenlender, A., Huntsinger, L., Guthey, G., Fairfax, S., 2004, Land trusts and conservation easements: Who is conserving what for whom?, *Conservation Biology* **18**(1):65-76.
- Milder, J. C., 2007, A framework for understanding conservation development and its ecological implications, *BioScience* **57**(9):757-768.
- Milder, J. C., Clark, S., 2011, Conservation development practices, extent, and land-use effects in the United States, *Conservation Biology* **25**(4):697-707.
- Milder, J. C., Lassoie, J. P., Bedford, B. L., 2008, Conserving biodiversity and ecosystem function through limited development: An empirical evaluation, *Conservation Biology* **22**(1):70-79.
- Miller, J. R., Groom, M., Hess, G. R., Steelman, T., Stokes, D. L., Thompson, J., Bowman, T., Fricke, L., King, B., Marquardt, R., 2009, Biodiversity conservation in local planning, *Conservation Biology* **23**:53-63.
- Natural Lands Trust, 2009, *Growing Greener: Conservation By Design*. https://natlands.org/wp-content/uploads/downloads/2011/10/GGBrochure2009_ImagesToCopy.pdf. Media, PA, in: .
- Nilon, C. H., Long, C. N., Zipperer, W. C., 1995, Effects of wildland development on forest bird communities, *Landscape and Urban Planning* **32**(2):81-92.
- Pejchar, L., Morgan, P. M., Caldwell, M. R., Palmer, C., Daily, G. C., 2007, Evaluating the potential for conservation development: biophysical, economic, and institutional perspectives, *Conservation Biology* **21**(1):69-78.
- R Development Core Team 2014, *R: A language and environment for statistical computing*, R Foundation for Statistical Computing, Vienna, Austria.
- Radeloff, V. C., Hammer, R. B., Stewart, S. I., Fried, J. S., Holcomb, S. S., McKeefry, J. F., 2005, The wildland-urban interface in the United States, *Ecological Applications* **15**(3):799-805.
- Radeloff, V. C., Stewart, S. I., Hawbaker, T. J., Gimmi, U., Pidgeon, A. M., Flather, C. H., Hammer, R. B., Helmers, D. P., 2010, Housing growth in and near United States protected areas limits their conservation value, *Proceedings of the National Academy of Sciences* **107**(2):940-945.
- Reed, S. E., Hilty, J. A., Theobald, D. M., 2014, Guidelines and Incentives for conservation development in local land-use regulations: guidelines for conservation development, *Conservation Biology* **28**(1):258-268.
- Riebsame, W. E., Gosnell, H., Theobald, D. M., 1996, Land use and landscape change in the Colorado mountains I: Theory, scale, and pattern, *Mountain research and development*:395-405.
- SAS Institute Inc., 2012, *SAS® 9.3* (SAS Institute, ed.), Cary, NC.
- SEWRPC, 2000, *Environmental Corridors: Lifelines of the natural resource base*, in: *Plan on it! A series of fact sheets on regional planning issues in Southeastern Wisconsin*.
http://www.sewrpc.org/SEWRPCFiles/LandUse/LandUseData/FactSheets/plan_on_it_environmental_corridors.pdf.

- SEWRPC, 2006, A regional land use plan for Southeastern Wisconsin: 2035. Planning Report 48, Waukesha, WI.
http://www.sewrpc.org/SEWRPCFiles/Publications/pr/pr-048_regional_land_use_plan_for_se_wi_2035.pdf.
- Smithson, M., Verkuilen, J., 2006, A better lemon squeezer? Maximum-likelihood regression with beta-distributed dependent variables, *Psychological methods* **11**(1):54-71.
- Tecklin, D. R., Sepulveda, C., 2014, The diverse properties of private land conservation in Chile: growth and barriers to private protected areas in a market-friendly context, *Conservation and Society* **12**(2):203.
- Thompson, R. H., 2004, Overcoming barriers to ecologically sensitive land management, *Journal of Planning Education and Research* **24**(2):141-153.
- Wade, A. A., Theobald, D. M., 2010, Residential development encroachment on U.S. protected areas, *Conservation Biology* **24**(1):151-161.
- Wallace, G. N., Theobald, D. M., Ernst, T., King, K., 2008, Assessing the ecological and social benefits of private land conservation in Colorado, *Conservation Biology* **22**:284-296.
- Wilson, J., Spinney, J., Millward, H., Scott, D., Hayden, A., Tyedmers, P., 2013, Blame the exurbs, not the suburbs: Exploring the distribution of greenhouse gas emissions within a city region, *Energy Policy* **62**:1329-1335.

Tables

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.

Table 1.

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
<i>mean:</i>		25.3		2.8		1.2		7.8		4.5		8.9	

Figure captions

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

Figure 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.

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

Figure 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).

Figure 1

Figure 2

Figure 3

Figure 4

Acknowledgements

This article is a product of the Global Challenges Research Team on Conservation Development, School of Global Environmental Sustainability, Colorado State University (<http://cd.colostate.edu>). We are grateful for funding from the USDA Forest Service, Rocky Mountain Research Station, School of Global Environmental Sustainability, Robert and Patricia Switzer Foundation, and National Association of Realtors. Ian Yesilionis and four anonymous reviewers provided valuable feedback on this manuscript.