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Effectiveness of conservation easements for reducing development and maintaining biodiversity in sagebrush ecosystems

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ABSTRACT

Conservation easements are the primary tool used globally by land trusts and governmental agencies to achieve conservation goals on private lands, but empirical evaluations of their effectiveness are lacking. Here we compared biodiversity in sagebrush ecosystems and recent rates of change in road and structure densities on properties with and without easements held by The Nature Conservancy in Wyoming, USA. To determine whether any differences between properties with and without easements were better explained by development pressure or by management practices, properties were stratified by low versus high residential development pressure and property managers were surveyed. In areas with high development pressure, easement properties had fewer structures and tended to have fewer, smaller roads than properties without easements. In the high-pressure areas, properties with easements also had greater use by some wildlife species than properties without easements. Regardless of easement presence, there was higher cover of exotic plant species and fewer mammal burrows in high than low-pressure areas. There were no significant differences in land management practices between properties with and without easements, but managers of properties with easements tended to seek management support more often than other managers. This may present an opportunity to provide support for specific management activities on easements to ensure that they continue to meet intended goals. Given the importance of easements as an alternative to nature reserves and the significant investment being made to acquire additional easements, it is essential to continue to evaluate whether easements are an effective tool in other locations.

1. Introduction

Conservation easements have become the primary protection tool used by land trusts and governmental agencies globally to achieve conservation goals on private lands (Stephens, 2001; Di Leva, 2002; Fishburn et al., 2009). In the United States, conservation easements are voluntary agreements between a land owner and a land trust in which the owner sells or donates their right to subdivide and develop their property (Merenlender et al., 2004). The goals of easements include protecting habitat for threatened and rare species, protecting water resources and ecosystem services, providing buffers near existing public lands, and creating corridors between conservation lands (Kiesecker et al., 2007; Rissman et al., 2007). Interest in the social, economic, and conservation impact of easements is increasing (Maciver et al., 2007). While the majority of easements are audited for compliance with easement restrictions related to development, few easements receive quantitative ecological monitoring to assess whether the easement meets intended conservation goals (Kiesecker et al., 2007).

The growing use of easements as a conservation strategy has led to increased scrutiny of how they work and what they intend to protect (Merenlender et al., 2004; Yuan-Farrell et al., 2005; Kiesecker et al., 2007; Rissman et al., 2007; Rissman and Merenlender, 2008). Most evaluations, though, have been broad in scope, describing only general intentions of easements. There have been few studies of the effectiveness of existing easements. Byrd et al. (2009) projected future residential development with and without easements in place, informing strategies for locating future easements. However, the actual development prevented by existing easements was not measured. Other spatial analyses have been used to identify which ecosystems, wildlife habitat, or other values intersect with easements or other protected private lands (Wallace et al., 2008;

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Gallo et al., 2009), but these analyses have not evaluated how easements may or may not be maintaining these values. Empirical evaluations of the effectiveness of conservation easements are needed, especially to address the question of what would have happened had the easements not existed (Ferraro and Pattanayak, 2006).

We evaluated whether conservation easements in Wyoming, USA have reduced development as intended and if these development restrictions correspond to differences in biodiversity between properties with and without easements. Our analysis focused on easements held by The Nature Conservancy (TNC), because these easements are chosen strategically to meet conservation goals (Kiesecker et al., 2007). Conservation goals are met primarily through the prevention of development and habitat fragmentation; most TNC easements allow activities such as ranching (Rissman et al., 2007). Specific terms vary among individual easements, but overall the easements place greater limitations on parcel subdivision and the construction of new roads and structures than state or local development regulations do. We compared properties with TNC easements to nearby properties without easements to address two questions about easement effectiveness. First, do recent rates of change in the densities of roads and structures differ between properties with and without easements? Second, does biodiversity differ between properties with and without easements? We chose several community and ecosystem characteristics to represent biodiversity: plant diversity and composition, shrub structure and vigor, soil cover, and wildlife use. Properties were stratified by low versus high residential development pressure to determine whether differences between properties with and without easements were explained by development pressure, and we tested for the direct effects of development pressure on biodiversity. We also surveyed land managers to determine if any differences in biodiversity measurements between properties with and without easements may be explained by differences in management rather than the development restrictions associated with easements.

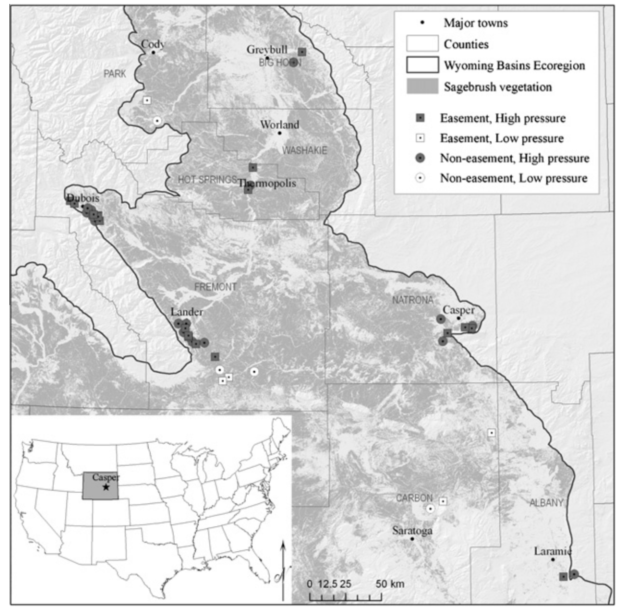

Fig. 1. Properties sampled in low and high development pressure areas within sagebrush ecosystems of the Wyoming Basins Ecoregion in Wyoming, USA.

2. Materials and methods

2.1. Study area

We studied privately-owned lands in the Wyoming Basins Ecoregion (WBE) in Wyoming (EPA, 2009; Fig. 1). The predominantly rural WBE is dominated by high-elevation semi-arid sagebrush vegetation with variable, rolling topography. Sagebrush ecosystems and sagebrush-obligate species in the WBE and elsewhere are being heavily impacted by energy and residential development (Knick et al., 2003; Gude et al., 2006; Naugle et al., 2011).

2.2. Sampling design

We sampled 23 properties with easements and 20 properties without easements to compare measures of development and biodiversity between the two classes. We stratified the properties by high or low pressure for residential development (Fig. 1). We estimated current development pressure for each property as high or low to capture coarse differences among regions within Wyoming using distances from towns and existing housing densities, factors that have been related to residential development rates in previous studies (Theobald, 2005; Gude et al., 2006). We measured the distance by road from each easement to the nearest major town of 1000 people or more (Fig. 1) using the Network Analyst extension of ArcGIS (Environmental Systems Research Institute, Redlands, CA). Housing unit density was summarized for the townships in which easements were located using census block data (US Census Bureau, 2001). A township is a standard US square-shaped land survey unit that measures 9.7 km on a side (~93 km^2). Properties in the high development pressure stratum were located within 36 km of towns, which corresponds to less than a 20-min drive from a major town, and within townships having more than 0.03 housing units per ha. Properties in the low-pressure stratum were more than 36 km from towns and within townships having less than 0.03 housing units per ha. Two easements were located close to a town where housing densities were low; these were categorized as high pressure based on nearby recent increases in development. The distance and density values used to categorize properties as having high or low development pressure were determined from qualitative data obtained from experienced real estate professionals.

In high-pressure areas, we sampled 18 properties with easements and 16 properties without easements, and in low-pressure areas we sampled five properties with easements and four properties without easements. Our sample size was small in low-pressure areas, because few easements are established where the current probability of residential development is low. Easement properties were selected first and properties without easements were randomly selected nearby. Easements within the WBE held by TNC that had at least 5 ha of *Artemisia tridentata* sagebrush shrubland and steppe ecosystems (Davidson et al., 2009) were eligible for sampling. In June 2008 we contacted the owners of the 29 easements, and 21 landowners representing 23 easements agreed to participate. The easements had been established between 1980 and 2005, with the majority created after 1993.

To randomly select privately-owned land parcels that were not under an easement, we used county parcel databases to generate a list of properties within the same township. In low-pressure areas, properties were randomly selected to be similar in size to the nearby easement. In high-pressure areas, properties were randomly selected across four size categories typical of these more developed areas: less than 4 ha, 4–16 ha, 16–65 ha, and greater than 65 ha. The sampling of parcel sizes differed between low and high-pressure areas to represent the typical variation present in each. In the high-pressure areas, properties with easements were typically larger than those without easements (516 versus 202 ha, on average). Non-easement properties excluded from sampling included those owned by the same landowner as a sampled easement

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property, those occurring within city limits, and those under easements held by other land trusts. We contacted the owners of 42 non-easement properties with sagebrush vegetation and 20 of these landowners agreed to participate, which was the factor that limited our sample size.

2.3. Road and structure density measurements

We measured recent (2006) and past (2001) road and structure densities on each of the 43 properties and determined the recent rate of change in road and structure densities. Rate of change between 2001 and 2006 was determined for all properties except six easements in high-pressure areas that were established after 2001. Using heads-up digitization techniques, we created GIS files of roads and structures present in both 2001 and 2006, using 1-m resolution USGS and National Agriculture Imagery Program digital orthophotos. Development was not measured for an earlier date, because only three of the easements had been established prior to 1994, the only other date for which historical imagery was available across the study area. We measured total road length and also applied a road buffer to estimate indirect ecological impacts. We buffered roads on both sides, using distances of 250 m in each direction for paved roads, 100 m for gravel roads, and 25 m for two-track dirt roads (Theobald, 2003). Roads and structures were associated with residential development, with the exception of one non-easement property having some roads associated with a small oil field. We counted numbers of structures per property and the land area occupied by structures. To be counted, structures were at least 5-m wide in one direction and included only houses and barns. To account for variation in property size, each of the measurements was divided by the property size to yield estimates of road density (m/ha), structure density (number/ha), percent area impacted by roads, and percent area occupied by structures.

2.4. Biodiversity measurements

We measured 27 variables representing compositional, structural, and functional components of ecosystem biodiversity in 10-m by 25-m macroplots (Table 1; Noss, 1990). We chose easily repeatable measurements for which variation would indicate changes in the characteristics of the ecosystem. Field sampling occurred from early July to early August in 2008. To locate sampling plots on each property, we generated random points at least 50 m apart in areas having *A. tridentata* sagebrush shrubland and steppe vegetation (Davidson et al., 2009), less than 25% slope, and elevation between 1100 and 2500 m. If the field visit revealed that a plot was not dominated by sagebrush vegetation, it was replaced with another random plot. On 37 of the 43 properties, three or four macroplots were sampled, depending on property size and time available for sampling. The remaining six properties had only one or two macroplots, due to limited areas of sagebrush vegetation. Statistical tests were based on mean macroplot values across each property.

Each sample was a 10-m by 25-m macroplot (0.025 ha) with nested subplots. In the macroplot we counted the number of mammal burrows and harvester ant mounds, and recorded all plant species found in a 10-min search. To estimate shrub canopy cover (by species, alive versus dead), we measured canopy intercepts (Canfield, 1941) on a 25-m tape stretched tightly along the midline of the macroplot. Three 1-m by 5-m shrub density subplots were located at 0–5 m, 10–15 m, and 20–25 m along one side of the transect. Within each we counted every shrub and recorded species and height for the top of the vegetative canopy (<5 cm, 5–25 cm, 25–50 cm,>50 cm), and recorded whether the shrub was alive or completely dead. For analysis, each shrub was assigned a height equal to the mid-point of the appropriate height range (e.g., a shrub in the 5–25 cm range was assigned a value of 15 cm). Percent live canopy was estimated from the four shrubs closest to each of three points along the transect (0 m, 10 m, 20 m) (one shrub with roots within each of four quadrants). Five 0.5-m by 1.0-m microplots were located at regular intervals opposite the shrub density subplots. In these, we estimated percent canopy cover (Daubenmire, 1959) of each plant species and percent cover of bare soil, soil crusts, and plant litter using seven percentage classes (<1, 1–5, 5.1–15, 15.1–25, 25.1–50, 50.1–75, 75.1–100). For analysis, we used the mid-points of the percentage classes to represent cover (e.g., 1–5% cover became 3%, 15.1–25% cover became 20%, and so forth) and averaged mid-points by species for the macroplot. For each species, we determined growth form (FGDC, 2008), native or exotic origin, and annual or perennial life span (USDA NRCS, 2009). We also counted the number of sagebrush seedlings in each microplot and averaged the counts to estimate density for the macroplot. Finally, we recorded wildlife dropping (pellet) presence in each microplot and determined macroplot pellet frequency based on the proportion of microplots with pellets. We calculated the Simpson diversity index (Simpson, 1949) for canopy cover of both native species and growth forms, using the "diversity" function in the open-source statistical package R (Oksanen et al., 2007). The following growth forms were included: needle-leaf tree, dwarf shrub, deciduous shrub, evergreen shrub, succulent shrub, fern, flowering forb, bunchgrass, rhizomatous grass, bryophyte, and lichen.

Many of the biological variables we measured are influenced by environmental gradients, so we determined a number of these for each macroplot (Table 2). Environmental variables were slope measured in the field, elevation obtained from a USGS 30-m digital elevation model, soil average water capacity and topsoil organic matter (USDA Natural Resource Conservation Service State Soils Geographic Database [STATSGO]), and average annual precipitation and temperature from 1951 to 2006 applied to a 4-km resolution spatial grid using the PRISM model (Daly et al., 2002; http://ClimateWizard.org).

2.5. Land management survey

We mailed a two-page survey to the 41 land managers in August 2008, following the field visits. The questions were meant to

Table 1
Biodiversity measurements on properties with and without conservation easements.

Characteristic	Measured variables
Plant diversity and composition	Number of native species, number of exotic species, Simpson index (native species), Simpson index (growth forms), native canopy cover, exotic canopy cover, annual forb canopy cover, perennial forb canopy cover, annual grass canopy cover, perennial grass canopy cover
Shrub structure and vigor	Live shrub canopy cover, proportion dead shrub canopy cover, shrub density, shrub vigor (% live canopy), shrub height, sagebrush live canopy cover, sagebrush density, sagebrush height, sagebrush seedling density
Soil stability and nutrient cycling	Total plant canopy cover, bare soil cover, plant basal cover, plant litter cover, soil crust cover (mosses and lichens), number of harvester ant mounds
Wildlife use	Pellet frequency (deer, antelope, rabbits), number of mammal burrows (ground squirrel, pocket gopher, badger)

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Table 2
Environmental characteristics of sampling plots on properties with or without easements or in high versus low development pressure areas. Means are followed by standard error in parentheses.

Environmental characteristics	Easement presence		Development pressure	
	Easement 71 plots	No easement 55 plots	High pressure 97 plots	Low pressure 29 plots
Elevation (m)	1958 (34)	1939 (46)	1905 (34)	2099 (18)
Mean annual precip (mm)	387 (12)	360 (12)	375 (10)	376 (17)
Mean annual temp (°C)	4.3 (0.2)	4.5 (0.3)	4.5 (0.2)	4.3 (0.1)
Soil water capacity (cm/cm)	0.117 (0.003)	0.115 (0.003)	0.115 (0.003)	0.121 (0.003)
Soil organic matter (%)	1.57 (0.04)	1.38 (0.03)	1.49 (0.03)	1.50 (0.10)
Slope (°)	12.6 (1.1)	13.3 (1.3)	13.9 (1.0)	9.8 (1.2)

determine whether any differences in our biodiversity measures may be related to management, as opposed to development pressure. Two questions asked whether invasive species had been controlled or if livestock had been grazed on the property during the past 3 years. We asked respondents to identify any organizations they had sought out for technical assistance or cooperative resource management; nine choices were provided that included local, state, and federal agencies, associations, or extension offices. Similarly, we asked whether managers had implemented any range improvement or wildlife enhancements on their own and to identify the project types (e.g., fence modification, water development, etc.). Finally, we asked whether biological monitoring contributed to their current management program.

2.6. Statistical analysis

We tested for differences in each development or biodiversity variable between properties with and without easements. We completed these tests separately in areas with high versus low development pressure, because we were expressly interested in whether easement effects differed with development pressure. We also tested whether any of the biodiversity variables were affected by development pressure, independent of easement presence. For all development and biodiversity analyses we used *F*-tests from one-way ANOVA based on linear models ($\alpha = 0.05$) and transformed response variables to meet model assumptions. Our study included two factors that might also have been analyzed using a two-way ANOVA; however, there is controversy related to the use of two-way ANOVA with unbalanced sample sizes such as that between our low and high pressure categories (Shaw and Mitchell-Olds, 1993; Hector et al. 2010). For the biodiversity variables, we used mixed-effects models fitted by maximizing the restricted log-likelihood, using the lme package of R (Pinheiro and Bates, 2000; R Development Core Team, 2009). We used mixed-effects models to control for spatial pseudoreplication (Robinson, 1991; Pinheiro and Bates, 2000). Here we sampled data from multiple macroplots within each property, so 'property' was included as a random effect in the models to control for the multiple samples per property and reduce the number of degrees of freedom to the number of properties rather than macroplots. This approach allowed us to retain the full range of variation in our field data. Environmental gradients may also influence biodiversity variables, so prior to testing for easement and development effects, we used the same mixed-effect model structures to test whether the six environmental variables described previously differed by easement presence or development pressure, since this could potentially confound our primary tests. There were no differences in environmental variables between easement and non-easement properties, but low-pressure areas tended to have higher elevation than areas with high development pressure ($F_{1,41} = 3.8$, $p = 0.06$; Table 2). Therefore, we included elevation as a predictor variable in these models and used sequential sums of squares to determine if development pressure explained additional variation not already explained by elevation differences. Given the exploratory nature of this study, we did not apply corrections for multiple tests to avoid failure to detect real differences (Roback and Askins, 2005).

We tested whether responses to the land management survey questions differed between managers of properties with or without easements. For the dichotomous survey questions we applied Fisher's tests using SAS 9.1.3 software (SAS Institute, Cary, North Carolina). We tested for differences in the number of groups that land managers selected for technical assistance and the number of improvement project types using linear models fitted with least squares estimation in R.

3. Results

3.1. Road and structure density

In areas with high pressure for residential development, properties with easements had a lower density of structures ($F_{1,32} = 4.7$, $p = 0.04$) and had smaller areas occupied by structures ($F_{1,32} = 4.7$, $p = 0.04$) in 2006 than properties without easements (Fig. 2a and b). There were no significant differences in road density or the area impacted by roads between properties with and without easements, but there was a tendency toward fewer roads and smaller area impacted by roads on properties having easements, in the areas with high residential development pressure (Fig. 2c and d). There were no differences in any of the four variables between properties with and without easements in areas with low development pressure.

On properties without easements in areas with high development pressure, road density and the area impacted by roads increased on average by 15% between 2001 and 2006 (standard error; se = 9%) and 198% (se = 197%), respectively (Fig. 3). In contrast, on properties with easements located within the same high-pressure areas, road density and impacted area increased by an average of only 2% during the same period (Fig. 3). In high-pressure areas, changes in structures were small on properties without easements, and properties with easements had no new structures at all (Fig. 3). In areas with low development pressure, the highest mean percent change among all four development variables was only 6%.

3.2. Biodiversity variables

Three biodiversity variables differed significantly between properties with and without easements, but only in areas with high pressure for residential development. The frequency of wildlife pellets was higher on properties with easements than on those without easements in high-pressure areas ($F_{1,32} = 5.1$, $p = 0.03$; Fig. 4a). These pellets were from mule deer (*Odocoileus hemionus*), white-tailed deer (*Odocoileus virginianus*), pronghorn antelope (*Antilocapra americana*), rabbits (*Sylvilagus sp.*), and jackrabbits (*Lepus sp.*). Sagebrush shrubs were shorter on easement than non-easement properties in high-pressure areas ($F_{1,32} = 4.7$, $p = 0.04$;

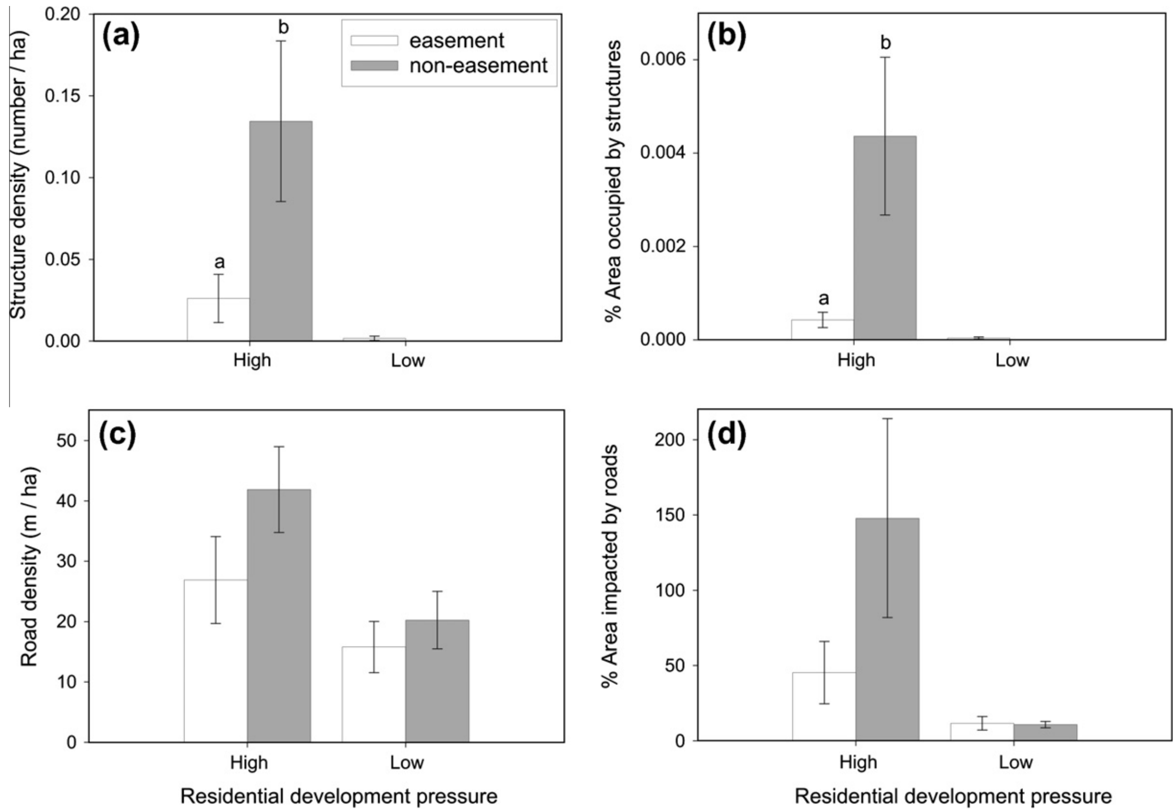

Fig. 2. Mean and standard error of (a) structure density, (b) percent area occupied by structures, (c) road density and (d) percent area impacted by roads in 2006 on properties with and without conservation easements in areas with high versus low residential development pressure. Statistically significant differences between easement status within development pressure classes ($p < 0.05$) are indicated by different letters.

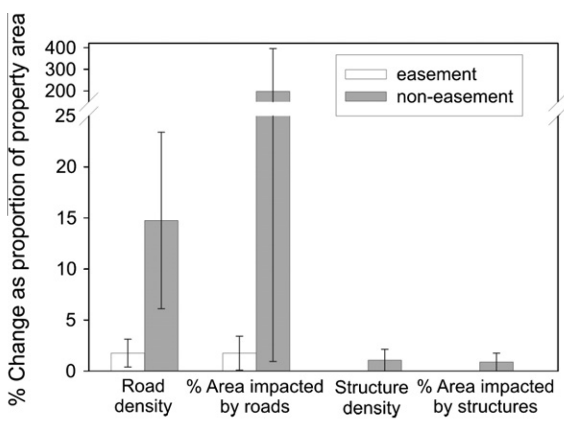

Fig. 3. Mean and standard error of the percent change from 2001 to 2006 in road density (m/ha), percent area impacted by roads, structure density (number/ha) and percent area occupied by structures on properties with and without conservation easements in areas with high pressure for residential development.

Fig. 4b). Sagebrush shrub densities were higher on easement than non-easement properties in high-pressure areas ($F_{1,32} = 4.1$, $p = 0.05$; Fig. 4c).

Five biodiversity variables differed significantly between areas with high versus low pressure for residential development, regardless of whether the properties had easements and after accounting for differences in elevation. Percent canopy cover of exotic plant species was greater in areas with high development pressure (mean 4.9, se 1.0) than in areas with low development pressure (mean 0.2, se 0.1) ($F_{1,41} = 4.1$, $p = 0.05$). There were more mammal burrows in low pressure (mean 2.5, se 0.5) than high-pressure areas (0.8, 0.2) ($F_{1,41} = 10.2$, $p = 0.003$). Mammal species using these burrows were ground squirrels (*Spermophilus sp.*), pocket gophers (*Thomomys sp.*) and badgers (*Taxidea taxus*). Sagebrush shrubs were taller in areas with high development pressure as compared with low-pressure areas ($F_{1,41} = 7.3$, $p = 0.01$), with a mean of 31.7 cm (se = 1.2) versus 24.5 cm (se = 2.4), as were shrubs overall ($F_{1,41} = 7.1$, $p = 0.01$; high: 29.9 cm, se = 1.1; low: 23.5, se = 2.0). Shrub densities were lower in areas with high development pressure than in areas with low development pressure ($F_{1,41} = 4.6$, $p = 0.01$), with a mean of 2.2 shrubs per m^2 (se = 0.2) versus 3.1 (se = 0.3).

3.3. Land management

The land management survey had a response rate of 59% (24 respondents). Fourteen respondents managed properties with easements and 10 managed properties without easements. Both groups were well-distributed spatially across the study area.

There were no significant differences in reported land management practices between properties with and without easements. Therefore, we did not explore possible relationships between these findings and the biodiversity measurements. Proportions of respondents indicating that weed control and livestock grazing had occurred during the past 3 years did not differ between properties with and without easements (Fig. 5). Proportions of respondents indicating that they had implemented range improvement or wildlife enhancements on their own or biological monitoring also did not differ between properties with and without easements (Fig. 5). Numbers of improvements reported also did not differ, averaging 1.2 for managers of properties with easements and 1.3 for managers of properties without easements. Managers of properties with easements tended to seek out organizations for

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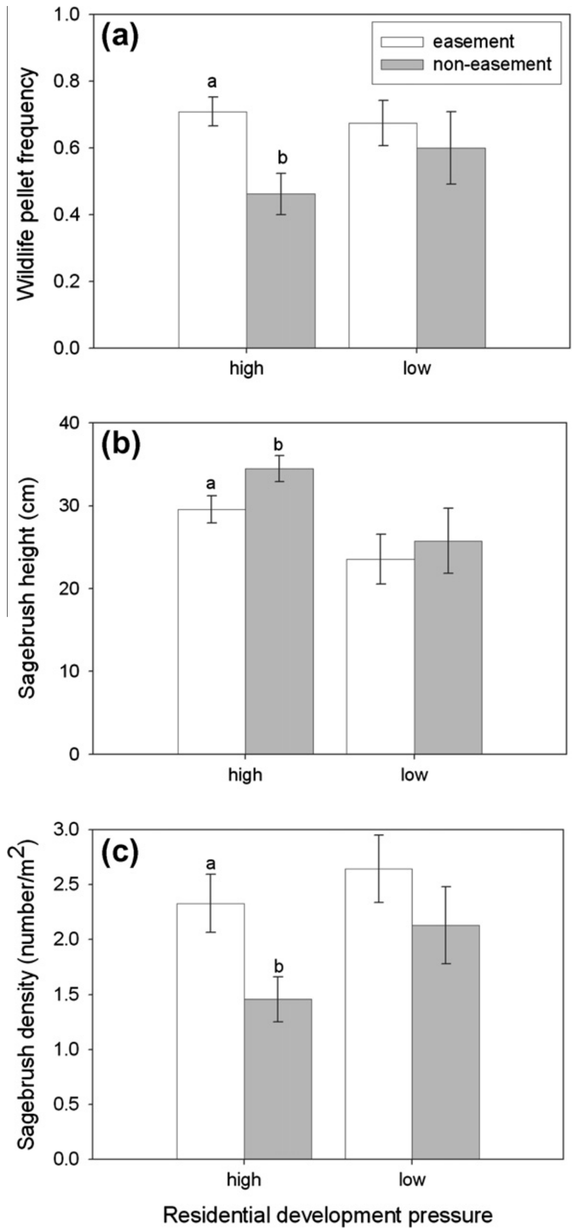

Fig. 4. Mean and standard error of (a) the frequency with which wildlife pellets were encountered, (b) sagebrush shrub height and (c) sagebrush shrub density on properties with and without conservation easements in areas with high versus low residential development pressure. Statistically significant differences between easement status within development pressure classes ($p < 0.05$) are indicated by different letters.

technical assistance or cooperative resource management more often than managers of properties without easements, but this difference was not statistically significant (Fig. 5). Easement managers sought out an average of 1.6 technical assistance organizations (se = 0.5), while non-easement managers sought out 0.5 organizations (se = 0.2), but this difference was also not statistically significant. Collectively, technical assistance organizations were sought out 23 times by easement managers and only five times for non-easement managers.

4. Discussion

We found that less development occurred on conservation easements than on neighboring properties without easements in high-pressure areas; thus easements are achieving their intended goal of reducing development in areas of Wyoming experiencing increased residential development. In low-pressure areas we found no differences, though we were limited by a small sample size in these areas. In areas under high pressure for residential development, properties with easements had fewer residential structures and tended to have fewer and less-developed roads than properties without easements. Even during a relatively short 5-year period, we found that easements tended to prevent development; had easements not been in place during this period in areas experiencing high development pressure, road densities may have increased by an average of 15% and land area impacted by roads may have doubled or quadrupled on some properties.

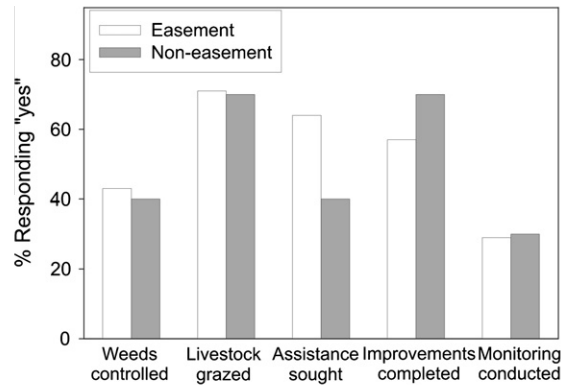

Fig. 5. Proportion of managers of properties with and without conservation easements reporting whether weeds were controlled, livestock grazing occurred, groups were sought out for technical assistance or cooperative resource management (assistance sought), range improvement or wildlife enhancements were implemented (improvements completed), and rangeland or other monitoring contributed to their current management program (monitoring conducted).

Because easements restrict development, it is not surprising that we found no difference in development between properties with and without easements in areas where pressure for residential and other development is currently low. However, establishment of easements in these types of areas should not be dismissed. Residential development continues to expand to previously undeveloped areas across the western US (Theobald, 2005; Gude et al., 2006). Other currently unexpected land use changes may also occur, such as the rapid development of wind energy facilities in Wyoming, which was unanticipated as recently as 5 years ago. For example, one biologically-important area in the remote and sparsely-populated Shirley Basin in Wyoming is quickly becoming dissected by industrial wind developments with which easements cannot compete economically. Establishing easements in high priority areas for biodiversity conservation before development is imminent can be completed at lower costs than in developing areas and thus potentially protect larger areas because of lower costs per unit of land (Copeland et al., 2007; Kiesecker et al., 2009).

In addition to restricting structure and road densities in areas with high residential development pressure, properties with easements had evidence of higher use by some wildlife species (deer, pronghorn, rabbits) relative to properties without easements. This suggests that, at least for these species, easements in areas experiencing residential development may be able to maintain similar habitat characteristics to those properties in less developed areas. This pattern may relate to lower densities of roads and structures on the easement properties; deer and other ungulates are known to avoid roads and other infrastructure (Rost and Bailey, 1979; Theobald et al., 1997; Sawyer et al., 2006). It may also relate to the typically larger size of properties with easements than those without easements in areas with high residential development pressure. For some species, a large property may provide some habitat, even within a landscape matrix that includes considerable residential development. However, we only measured wildlife occurrence in this study, not abundance or breeding success, and we did not distinguish among ungulates and lagomorphs here, which may have shown different responses if treated separately. Additionally, an isolated undeveloped area may not provide sufficient habitat for other species. The shorter, denser sagebrush shrubs that we observed on properties with easements in high-pressure areas may be related to a higher proportion of black sagebrush (*Artemisia nova*) that occurred on these easement properties (24% of total sagebrush cover, as compared to 4% on non-easement properties). Black sagebrush is shorter and grows more densely than the other sagebrush species measured in this study. Other possible explanations include increased browsing by wildlife species such as mule deer and pronghorn antelope or differences in soil productivity or microclimate not captured by environmental gradients we measured, but our study did not provide evidence for these mechanisms.

The amount of development in the surrounding landscape had a greater effect on some biodiversity variables than did the existence of a conservation easement, demonstrating that while easements can limit development within their boundaries, plants and animals on these properties are also affected by conditions within the surrounding landscape. We found this pattern for exotic plant species, which had higher canopy cover in areas with high pressure for residential development regardless of easement presence. This might be explained by higher amounts of soil disturbance from roads and buildings in these more developed areas that have allowed exotic plants to become established in larger numbers, facilitating their spread to nearby properties (Hobbs and Huenneke, 1992), or by increased propagule pressure associated with human traffic. There were also fewer mammal burrows in high-pressure areas, independent of easement presence. This could be related to increased predation on small mammals by domestic cats and dogs in areas with high densities of residential development (Odell and Knight, 2001; Maestas et al., 2003), but we did not measure predation in this study. Taller and less dense shrubs in the high development pressure areas did not appear to be related to differences in shrub species composition, as described for sagebrush shrubs on properties with and without easements. These differences in shrub height and density might be related to differences in wildlife browsing or to differences in soil productivity or microclimate that were not captured by environmental gradients we measured, but our study did not provide evidence for these mechanisms. Many of the biodiversity variables we measured showed no relationship with either easement presence or development pressure. Some of these variables may not be affected by residential development and may be better explained by finer scale variation in climate, soils, and topography than was measured in this study. The lack of differences may also be related to a short time period since development occurred on properties without easements; many biological features may not have had time to respond to the increased disturbance.

Biological conditions on properties with and without easements may have differed before easements were established or residential development occurred, although we do not expect that these differences would show a consistent bias because of the way easements are selected and the close proximity of properties with and without easements. The easements included in this study occurred within priority conservation areas and were accepted as easements because the properties included species and plant communities considered to be conservation targets, not because of the condition of the vegetation as measured in this study. TNC uses ecoregional planning to identify priority conservation areas, which are a collection of places that will maintain the biodiversity of an ecoregion if conservation targets within them are protected (Groves et al., 2002). All but one of the easements included in the study were donated and thus easements were initiated by the owner of the property; TNC did not seek out these specific properties but rather accepted easements because these properties were within priority conservation areas. Nearly all of the properties without easements occurred within the same conservation areas as the properties with easements. Thus properties with and without easements likely reflect similar environmental conditions and biological compositions.

Results of the land management survey suggest that management practices do not differ between properties with and without easements. Land management practices are not restricted by the easements considered here, so had we found differences it could have suggested that management philosophies differ between those who manage properties with and without easements. However, there was a tendency for managers of properties with easements to seek land management support from organizations more often than those managing properties without easements. This may provide an opportunity to promote specific management activities on easement properties. In the future, it may be important to initiate management projects on easement properties that are aimed at maintaining and improving their biodiversity, to ensure that these conservation investments continue to meet their intended goals.

Our results suggest that the easements we studied are effective at restricting development and may have related benefits for some wildlife species, but it is not known if this applies to easements generally. TNC does not, in most cases, have the data to answer this question (Kiesecker et al., 2007). While our results suggest a positive role of easements, we must be cautious about extrapolating our results to other places. Our study was completed for TNC easements in sagebrush ecosystems of the US; findings may differ for other ecosystems, other types of easements, and for other private land protection mechanisms. Conservation easements are the primary tool used by land trusts to preserve habitat and open space in the US, and they have grown in popularity outside the US, for example in Latin America and Europe, where they are called conservation covenants. As part of the Convention of Biological Diversity many countries have agreed to preserve 10% of each ecosystem (CBD, 2010), so easements could become a mechanism even more widely used outside of the US. Easements are less costly than fee acquisitions, as property taxes alone may exceed the costs of annual compliance monitoring. For example, for TNC's Wyoming Chapter, 2009 monitoring costs averaged $700 US per easement and are covered by an endowment fund to which a payment is made each time an easement is established. Given the importance of easements as an alternative to nature reserves and the significant financial investment being made to acquire additional conservation easements, it is essential to evaluate whether easements are an effective tool. Conservation generally has a record of failing to evaluate the effectiveness of its initiatives (Ferraro and Pattanayak, 2006). When it comes to easements, this failure is especially crucial, as public funds and tax breaks are often involved. Land trusts should work to ensure that the public trust is well served.

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