Estimating the Effect of Protected Lands on the Development and Conservation of Their Surroundings

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Abstract: *The fate of private lands is widely seen as key to the fate of biodiversity in much of the world. Organizations that work to protect biodiversity on private lands often hope that conservation actions on one piece of land will leverage the actions of surrounding landowners. Few researchers have, however, examined whether protected lands do in fact encourage land conservation nearby or how protected lands affect development in the surrounding landscape. Using spatiotemporal data sets on land cover and land protection for three sites (western North Carolina, central Massachusetts, and central Arizona), we examined whether the existence of a protected area correlates with an increased rate of nearby land conservation or a decreased rate of nearby land development. At all sites, newly protected conservation areas tended to cluster close to preexisting protected areas. This may imply that the geography of contemporary conservation actions is influenced by past decisions on land protection, often made for reasons far removed from concerns about biodiversity. On the other hand, we found no evidence that proximity to protected areas correlates with a reduced rate of nearby land development. Indeed, on two of our three sites the development rate was significantly greater in regions with more protected land. This suggests that each conservation action should be justified and valued largely for what is protected on the targeted land, without much hope of broader conservation leverage effects.*

Keywords: agricultural abandonment, agricultural landscape in transitions, AgTrans, conservation easements, Coweeta Hydrologic Laboratory, deforestation, fee simple, Harvard Forest, land conversion, urban and exurban development

Estimación del Efecto de Áreas Protegidas sobre el Desarrollo y la Conservación de sus Alrededores

Resumen: *El destino de terrenos privados es ampliamente visto como una clave para el destino de la biodiversidad en muchos sitios del mundo (Scott et al. 2001). Las organizaciones que trabajan para proteger la biodiversidad en terrenos privados a menudo esperan que las acciones de conservación en un terreno impulsarán acciones de los propietarios circunvecinos. Sin embargo, pocos investigadores han examinado sí las tierras protegidas propician la conservación en las cercanías o cómo afectan los terrenos protegidos al desarrollo en el paisaje circundante. Mediante el uso de conjuntos de datos espaciotemporales de la cobertura de suelo y la protección de tierras en tres sitios (oeste de Carolina del Norte, centro de Massachussets y centro de Arizona), examinamos si la existencia de un área protegida se correlaciona con un incremento en la tasa de conservación de terrenos cercanos o con un decremento de la tasa de desarrollo en terrenos cercanos. En todos los sitios, las áreas recién protegidas tendieron a agruparse cerca de áreas protegidas preexistentes.*

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Esto puede implicar que la geografía de las acciones de conservación contemporáneas está influida por decisiones pasadas respecto a la protección de tierras, a menudo tomadas por razones lejanas a la preocupación por la biodiversidad. Por otra parte, no encontramos evidencia de que la proximidad a áreas protegidas se correlacione con una reducción de la tasa de desarrollo en terrenos cercanos. De hecho, la tasa de desarrollo en dos de nuestros tres sitios fue significativamente mayor en regiones con más terrenos protegidos. Esto sugiere que cada acción de conservación debe ser justificada y valorada principalmente por lo que está protegido en el terreno en cuestión, sin mucha esperanza de mayores efectos que impulsen la conservación en los alrededores.

Palabras Clave: abandono agrícola, AgTrans, Bosque de Harvard, concesiones para la conservación, conversión de suelo, deforestación, desarrollo urbano y exurbano, dominio pleno, Laboratorio Hidrológico Coweeta, paisaje agrícola en transición

Introduction

A central challenge for conservation is to halt or manage land conversion so that natural landscapes are preserved for native biodiversity and other ecosystem services (Scott et al. 2001). The United States, Europe, and other regions use a mix of government reserves and land-trust activities to maintain natural landscapes. In the United States land protection is big business, with $2.7 billion having been invested in 2003 alone (Pidot 2005). The form of this investment can be either the outright acquisition of land or the purchase of conservation easements, which are legal contracts that maintain the land as private but restrict development so that conservation needs are met. In addition, a variety of tax and institutional incentives exist to create a disincentive to development at certain sites, such as those currently actively managed for timber or agriculture (Kluender et al. 1999; Ruhl 2000).

It is widely believed that development and land conversion are happening so rapidly in many parts of the United States that private land protection will not be able to keep pace (cf. Ferraro & Pattanayak 2006). As an alternative to this gloomy portrait, some land-trust organizations hope they can achieve gains not just through the immediate purchase of land or easements but through a leverage effect. Leverage is the idea that a few critical acts of land protection can affect the attitudes and decisions of neighboring landowners (cf. Gustanski & Squires 2000; McLaughlin 2002). This idea is sometimes discussed by land-trust organizations when they decide where to act (Fairfax 2005), but it has rarely been tested empirically. We used observational data to evaluate two critical components of the concept of leverage: the effect of protected areas on future protection of nearby land and the effect of protected areas on future development of nearby land. We use the word *protected* to signify an area that is protected permanently from conversion of natural land cover to a more developed land use.

The concept of leverage suggests that acts of land protection at one location may change neighboring landowners' attitudes, prompting them to consider protecting their land from conversion. Additionally, conservation organizations often incorporate concerns about the connectivity of protected areas into their planning decisions (e.g., Noss 2003). One thus might expect that newly protected areas will tend to be near existing protected areas. An alternative hypothesis is that newly protected areas are no more likely to be near existing protected areas than expected by chance. This hypothesis is consistent with the opportunistic nature of many conservation actions (Levitt 2005) and reflects the diversity of goals across conservation groups (Pidot 2005), which range in focus from biodiversity to ecosystem services to aesthetics to historical preservation. Given this diversity of goals, we did not pursue the question of whether conserved areas are meeting their stated conservation purpose, which varies considerably, but instead we asked how spatially aggregated conserved areas are to one another.

The concept of leverage also predicts that as the proportion of protected area increases in a region, landowners may become more conservation minded and less inclined to convert their land to other uses (cf. Merenlender et al. 2004). Therefore, one would expect the correlation between the proportion of neighboring lands protected and the probability of conversion at a site to be negative, after accounting for other confounding factors. Alternatively, permanently protected lands may serve as an amenity that increases the potential for land conversion on neighboring parcels (Mansfield et al. 2005; Armsworth et al. 2006). Thus, an alternative hypothesis is that the correlation between the proportion of neighboring lands protected and the probability of conversion at a site could be statistically indistinguishable from zero, if the two effects counteract each other, or even positive.

We performed a multisite analysis of private-land conservation in the United States, quantitatively dissecting spatial patterns of land protection and the possibility of leverage impacts in Massachusetts, Georgia, and Arizona. To our knowledge this is the first such multisite analysis, but we acknowledge our intellectual debt to earlier studies and commentary (e.g., Shogren et al. 1999; Geisler & Daneker 2000; Ferraro & Simpson 2002; Polasky et al. 2005).

Study Sites

We chose three sites to examine contrasting land-use histories and patterns of land protection, allowing for greater generality of our findings than if we had examined only one site. For clarity when we refer to a site, we mean one of our three study sites in its entirety. We refer to a specific location within a site as an area.

The Coweeta site (in Otto, North Carolina) was in the southern Appalachian Mountains (Fig. 1) and corresponded to the boundaries of Macon County (1340 km^2, hereafter Macon). Historically, the flat areas of the landscape were cleared for agriculture and the steep portions were logged (Salstrom 1994; Davis 2000). Agricultural abandonment took place after World War II (DeJong 1968), and the abandoned land reforested, either through natural establishment or planting of pine plantations (Oosting 1942; Davis 2000). Through federal purchase of abandoned land along with land swaps, large areas of this young forest were incorporated into the U.S. Department of Agriculture's Forest Service (USDA-FS). Since 1970 forests have been fragmented into smaller patches owing to the parceling-up of larger landholdings to meet the demand for real-estate development (Wear & Bolstad 1998). There are relatively few conservation trusts active in the region in part because the area is still rural and because of a public mistrust of conservation.

The North Quabbin region (Petersham, Massachusetts) is in the central uplands of Massachusetts, and its towns' boundaries (Fig. 1) formed our site (1840 km^2, hereafter

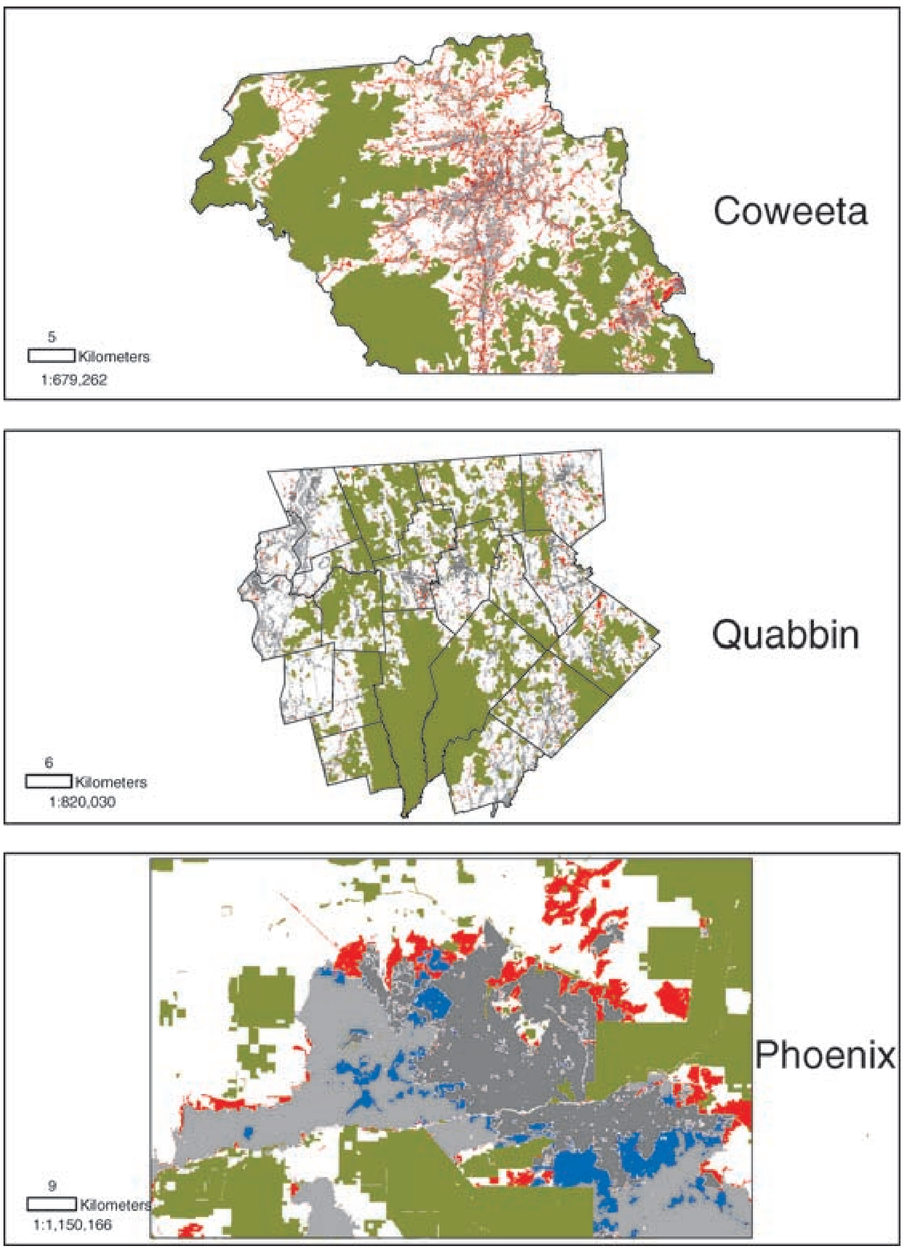

Figure 1. Loss of natural habitat through development at three sites in the United States. Each map shows older development (gray), loss of agricultural fields (blue), loss of natural habitat (red), and protected areas (green).

Quabbin). The extent and intensity of agriculture in this region was greater than near Macon, with some 60% of the landscape cleared (Hall et al. 2002). After widespread agricultural abandonment in the late nineteenth century, fields were reforested with a mix of natural and planted regeneration (Foster & Aber 2004). In contrast to Macon the bulk of the land remained in small holdings (Kittredge et al. 2003; McDonald et al. 2006). Forest fragmentation due to an expansion of developed land has become a major conservation concern in the past few decades, especially in the east near the Boston-Worcester metropolitan area (Massachusetts Audubon 2003). There is a wide diversity of conservation trusts, perhaps due to the historical strength of the land-trust movement in Massachusetts and the site's "wilderness" appeal (Conuel 1991).

Our central Arizona site was the greater Phoenix urban area (7930 km^2, hereafter Phoenix), which we defined as areas within approximately 50 km of downtown Phoenix (Fig. 1). Irrigated agriculture started in the early twentieth century, and remains a major economic asset of the region. Rapid urban growth has spread from the Phoenix core outward, encroaching into previously agricultural areas and partially surrounding major blocks of protected public lands. There is a diversity of conservation groups seeking to protect natural habitat and the remaining agricultural areas (Luckingham 1989).

Methods

Land-Cover Data

For each site we obtained land-cover images for two time periods, roughly bracketing the decade of the 1990s. Nevertheless, because land-cover data for this project were drawn from existing land-cover databases developed by each long-term ecological research site, there is some variation in the timing of the two land-cover images. Where necessary, we corrected for this by calculating rates on an annual basis.

Land-cover data for Macon was classified from Thematic Mapper Imagery with a resolution of 30 m. The 1992 National Land Cover Database (NLCD) was obtained from the Multi-Resolution Land Characteristics (MRLC) Consortium, which used a supervised classification technique to classify Thematic Mapper Imagery into discrete land-use categories (Vogelmann et al. 2001). A 2001 image was obtained from the NLCD that was created with classification-tree approaches designed to be consistent with the 1992 classification. Nevertheless, the inclusion of information about the road network into the classification process for the 2001 NLCD appears to have made the resulting classification much more sensitive to roads, which may artificially increase the land-use changes calculated by comparing the 1992 and 2001 NLCD (cf. Homer et al. 2004). Furthermore, NLCD imagery can occasionally miss very-low-density exurban settlements, particularly in the 1992 classification (Theobald 2003). To further increase temporal consistency of the classification, we lumped the classification to approximately an Anderson level-I scheme (Anderson et al. 1976) that contained four classes: forest, water, developed, and sparse vegetation (which included agriculture and more suburban land uses such as lawns).

Land-cover data for Quabbin was taken from approximately 0.5-m aerial photos, classified with photogrammetry techniques by the Resource Mapping Project at the University of Massachusetts. Information from 1985 and 1999 was downloaded from MassGIS (http://www.mass.gov/mgis/). The original classification scheme with 23 classes was lumped into four classes (forest, water, developed, sparse vegetation). To match the spatial resolution of the data from the other two sites, we resampled the Quabbin data to a 30-m resolution with a nearest-neighbor resampling algorithm.

Land-cover data for Phoenix were classified from Thematic Mapper and Enhanced Thematic Mapper images from 1985 and 2003. The classification was performed with a supervised, maximum likelihood classification with a 22-category scheme based on the NLCD classification scheme. We lumped the classification to four classes: natural cover types (similar to forest class for other sites), water, developed, and sparse vegetation.

Protected-Area Data

For all three sites land was defined as protected if it had permanent protection from conversion of natural land cover and thus met the criterion for status 1, 2, or 3 under the GAP biodiversity management categories. This definition includes areas with natural land cover that may nevertheless be managed in ways that harm facets of their conservation value. State and federal area boundaries for Macon were obtained from a larger North Carolina data set, available from the North Carolina Center for Geographic Information and Analysis (http://cgia.cgia.state.nc.us/). Five major land conservation organizations work in Macon County: The Nature Conservancy, Highlands-Cashiers Land Trust, Land Trust for the Little Tennessee, North Carolina Rail-to-Trails, and Appalachian Trail Conservancy. These five agencies were contacted, and we obtained the location, boundaries, and acquisition dates for all conserved parcels. Personal experience of one of us (T.G.) suggests that these four trusts control the preponderance of NGO-controlled conservation parcels in the county, but the possibility exists that a few parcels held by small trusts were missed by our analysis.

Unlike most states Massachusetts requires conservation easements to be registered with the Commonwealth (Pidot 2005), which greatly facilitated our data-collection task at Quabbin. Work by Golodetz and Foster (1997) and N. Malizia, G. Motzkin, and D. Foster (unpublished data) provided a baseline map of protected habitat. The date of parcel acquisition recorded is only accurate to approximately 2 years, because of details with how the state tracks creation of easements. There are five trusts (Acquisition of Conservation Easement properties, Massachusetts Audubon Society, Mount Grace Land Conservation Trust, New England Forestry Foundation, and The Trustees of Reservations) and several state and municipal agencies active at Quabbin.

State and federal land-cover data for Phoenix were obtained from a file maintained by the Arizona Land Resource Information System. Bureau of Land Management lands were not considered protected until after the Federal Land Policy Management Act of 1976, which halted sale of BLM lands to private landowners. This file also contained the boundaries of Native American Reservations, which make up a significant portion of the southeastern Phoenix region. We considered reservation lands protected because they are primarily managed for natural land cover, although occasional developments do occur. We contacted the 18 most active trusts in Arizona and obtained data from all of those known to operate in Phoenix, including Arizona Open Land Trust, Black Mountain Conservancy, Desert Foothills Land Trust, McDowell Sonoran Land Trust, Oracle, Superstition Area Land Trust, and The Nature Conservancy. For each trust we obtained the boundaries and acquisition dates of all protected parcels.

Analyses

To answer questions about whether protected land was located near previously protected areas, we analyzed the distribution of distances from newly protected areas to previously protected areas. A relatively sparse sample of 0.5% of the cells in a landscape was randomly selected from each site's land-cover maps. To avoid sampling urban locations, this sample included only cells that were either in natural cover (e.g., forest) or in sparse vegetation cover. Rather than using all of the millions of cells in each image, we took a random sample to avoid some of the inferential problems that occur when calculating statistics with very large sample sizes (cf. Guisan & Zimmermann 2000).

For our distributional analysis we calculated the distance from every sampled, unprotected pixel to the nearest area in the raster map protected before 1990. This formed the "baseline" distribution of distance to protected areas. Against this baseline we examined newly protected areas for two time periods: between 1990 and 2000 and between 2000 and 2005. For each sample pixel protected between 1990 and 2000, we calculated the distance to the nearest area in the raster map protected before 1990. This gave us the distribution of distance from newly protected areas (established 1990–2000) to previously protected areas. Similarly, we calculated the distance from sample pixels protected after 2000 to the nearest area in the raster map protected before 2000. This gave us the distribution of distance from newly protected areas (established after 2000) to previously protected areas. Distributions were estimated in SPLUS using kernel-density estimation with a normal-kernel and cross-validated bandwidth selection (Venables & Ripley 1999).

To answer questions about how land conservation affects the course of land conversion at each site, we constructed a formal statistical model for each site. The data set was taken from the sampled cells described above. Because protected areas are not converted (by definition), we used only Set 1 for this analysis. The dependent variable of interest was the probability of unprotected land being converted over the study interval, which varied by site (Macon, 9 years; Quabbin, 14 years; Phoenix, 18 years). *Conversion* was defined as a pixel changing from natural cover to sparse vegetation/developed or from sparse vegetation to developed. Potential explanatory variables in the model included slope, calculated from NASA SRTM data; distance to the nearest road, calculated from Tiger 2000 road data (essentially all paved roads; road categories A1, A2, A3, and A4); distance to the nearest stream, calculated from the National Hydrography Dataset (1:24,000 scale, all features labeled "stream/river" or "lake/pond"); and change in housing density, calculated from Wildland-Urban Interface data (Radeloff et al. 2005), which gives the change in housing density from the 1990 census to the 2000 census. Using the land-cover data, we calculated the proportion of developed area at the beginning of the time interval in a series of circular buffers (125-m, 250-m, 500-m, 1-km, 2-km, 4-km radius). Similarly, the proportion of protected area at the beginning of the time interval was calculated in the same series of circular buffers. When fitting the regression, only two buffer variables were allowed to enter the regression: one buffer of proportion developed and another of proportion protected. This procedure selected the buffer distances with the greatest explanatory power, as measured by the AIC. The regression was fit in an autologistic regression framework that took into account spatial autocorrelation, following the methodology of Augustin et al. (1996), such that

$$\ln\left(\frac{p}{1-p}\right) = \boldsymbol{\beta}\mathbf{X} + \varepsilon,$$

where p is the probability of land conversion, $\mathbf{X}$ is a vector of the potentially explanatory variables described above, $\boldsymbol{\beta}$ is a vector of fitted regression coefficients, and ϵ is a spatially correlated error term of the moving-average type. The neighborhood of significant autocorrelation in the process of land conversion was estimated with joint-count statistics (cf. McDonald & Urban 2006) as 250 m in Macon, 500 m in Quabbin, and 750 m in Phoenix. Within this neighborhood, the autocorrelation term was inverse-distance weighted, which matched the shape of the correlogram.

Results

Macon had several large blocks of protected areas (46.2% of site total area). These areas comprised the Nantahala National Forest and were mostly in rocky, high-elevation areas (Fig. 1). Land conversion (i.e., from forest to another land cover) occurred along major transportation corridors at lower elevation, particularly near the towns of Franklin and Highlands. Developed land increased sixfold from 1992 to 2001, from 0.8% to 5.8%, implying an average annual loss of 12.6 km^2 of natural habitat. Quabbin had one large block of protected habitat, the watershed of the Quabbin Reservoir of Boston (Conuel 1991), and a dispersed network of smaller patches covering much of the study area (38.7% of site total area). Land conversion appeared to be more frequent near the eastern edge of the study area, perhaps because of its greater proximity to Boston. Developed land area increased from 5.7% to 7.4% from 1985 to 1999, for an average annual loss of 2.7 km^2. Phoenix had large blocks of protected area surrounding the urban core to the south and east, owing to the Gila River Indian Reservation and Tonto National Forest, respectively (26.8% protected). Loss of natural cover was greatest north of Phoenix, whereas loss of agriculture was greatest to the west and southeast of the city. From 1985 to 2003, developed land increased from 14.5% to 25.4%, making Phoenix the most urban of our three sites; on average, 28.7 km^2/year of natural habitat were lost in Phoenix.

The majority of protected area in Macon (Fig. 2) consisted of opportunistic purchases by the USDA-FS of previously harvested, high-elevation areas from private

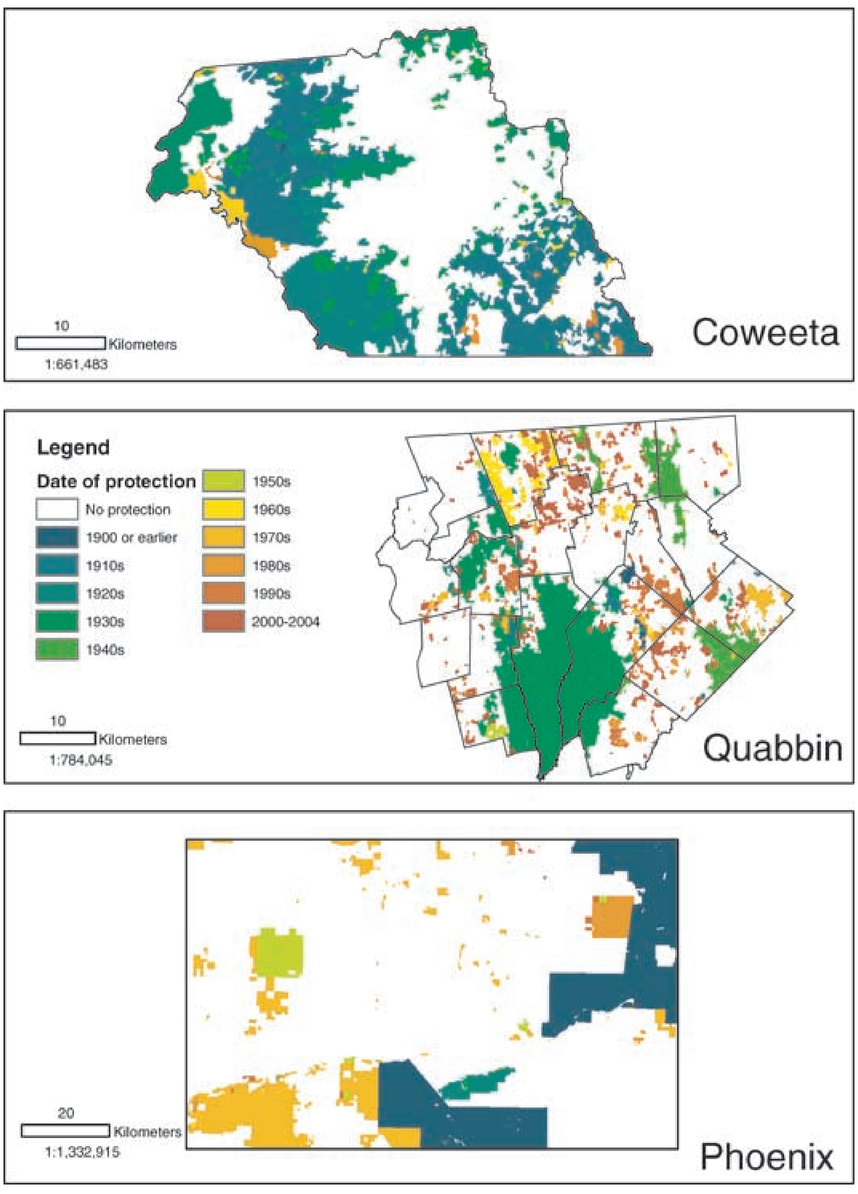

Figure 2. Establishment of protected areas at three U.S. sites. Each map shows protected areas color-coded by establishment date. Areas of unknown establishment date are gray.

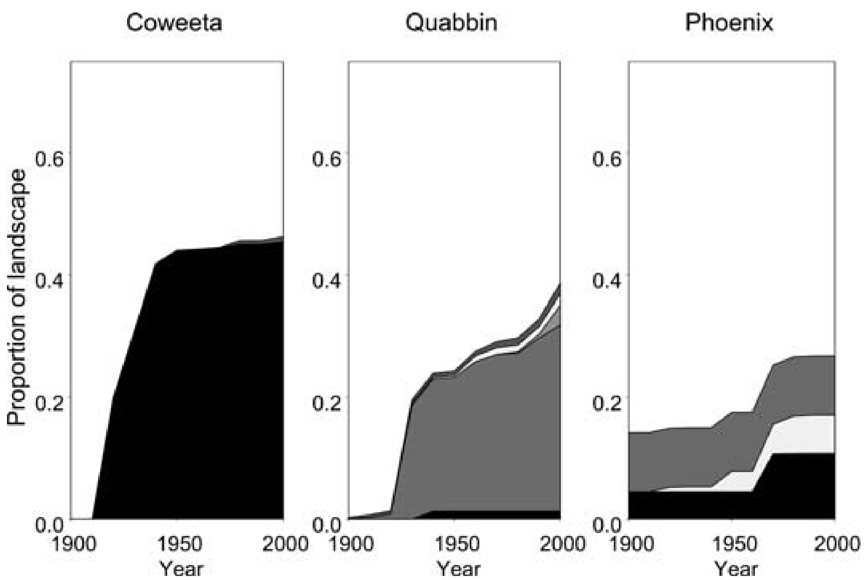

Figure 3. Protected area by ownership since 1900. Chart for each site, shows the proportion of land protected by different groups: federal (black), fee-simple NGO (dark gray), owned by state (gray), easement NGO (light gray), and municipal/county (white). Coweeta is dominated by federal ownership, Quabbin by state ownership, and Phoenix by a mix of federal, state, and municipal ownership.

landowners, especially timber companies. The big blocks of protected area in Quabbin surrounded major water resources, such as the Quabbin Reservoir (Conuel 1991). There were significant numbers of small conservation easements in the northern portion of the study area. Patterns in Phoenix were similar to Macon, with the majority of protected area at high elevations, divided among the Bureau of Land Management (BLM), USDA-FS, and several Native American reservations.

Trends in the total area protected over time (Fig. 3) showed that all three sites had the majority of their protected land established either before or early in the twentieth century. The protected landscape in Macon was dominated by USDA-FS land acquired mostly during the 1910s and 1920s. Inholdings and adjacent parcels were bought from 1970s to 1990s, with a shift toward smaller acquisitions after 2000. The protected areas of Quabbin were somewhat more diverse in ownership, with the dominant state-owned lands, acquired mostly in the 1930s and 1940s, augmented by municipal, federal, and conservation-organization lands. Conservation easements have become common in Quabbin since 1980. The federal lands in Phoenix were acquired and established after the Mexican-American war, with the largest change in conservation status due to the new protection afforded to BLM lands by the Federal Land Policy and Management Act of 1976.

The distribution of distance from newly protected areas to the nearest previously protected area was similar for all three sites in the 1990s, but varied in the 2000s (Fig. 4). The distribution for protected areas for 1990–2000 in Macon (dotted line) was higher at small distances than the landscape as a whole (solid line), implying that conserved areas tended to be close to other conserved areas. From 2000 onward, however, land protection in Macon seemed to have taken place in locations far from existing protected areas, confirming the results observed in Fig. 2. In contrast, in Quabbin land protection for the 1990s and 2000s seemed to occur primarily near existing protected areas. Although newly protected areas may not be strictly adjacent to previously protected areas (Fig. 2), they were usually within 1 km. Results for Phoenix were similar to those for Quabbin for the 1990s. Not enough protection occurred in the 2000s in Phoenix for statistical analysis.

The most important factor controlling land conversion (i.e., loss of natural cover or open space) in Macon was the distance to a road, with a doubling in the distance to a road decreasing the odds of land conversion by a factor of 2.0 (Table 1). Slope was also important, with sites on steeper slopes less likely to be developed, as was distance to stream, with sites closer to streams being more likely to be developed. The proportion of protected area in a 2-km buffer was a significant predictor of development probability, with a 10% increase in protected area increasing the odds of conversion by a factor of 1.1.

The most significant factor controlling land conversion in Quabbin (Table 1, middle panel) was the percent development within 125 m, with a 10% increase in the percent development in the surroundings increasing the odds of conversion by a factor of 1.34. Housing density was another significant variable, with a greater increase in housing density leading to a greater likelihood of land-cover conversion. Similar to Macon, distance to road was also a predictor of probability of land conversion for Quabbin, with a doubling in the distance to a road decreasing the odds of land conversion by a factor of 1.33. The proportion of protected land in any buffer zone did not have a significant relationship with the probability of land conversion.

For Phoenix the percentage of land developed within 500 m of the sampled cell was the most important predictor of probability of land conversion. A 10% increase in the percent development in the surroundings increased

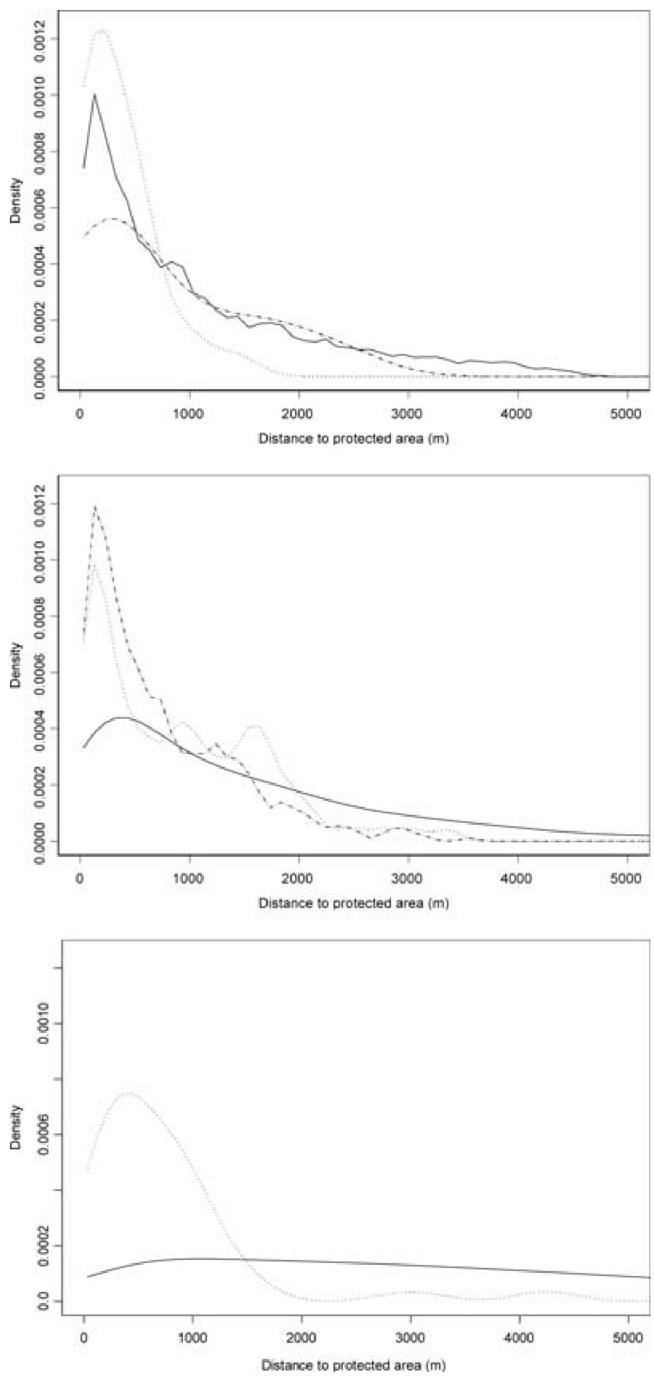

Figure 4. Proximity of new protected areas to existing protected areas in three sites in the United States. Distribution of distances from preexisting protected lands to lands protected from 1990 to 2000 (dotted) and lands protected after 2000 (dashed) for Macon (top panel), Quabbin (middle panel), and Phoenix (bottom panel). The distribution of distances from preexisting protected lands for the remaining landscape is shown as a solid black line. The distribution of distances is shown on the y-axis with a probability density function, a continuous measure of the distribution. See text for details.

the odds of conversion by a factor of 1.97. The next most significant variable was the housing density change, with areas that had the greatest increase in housing density having the highest likelihood of land conversion. Distance to road was also important, with a doubling in the distance to a road decreasing the odds of land conversion by a factor of 1.06. Finally, proportion of protected area in a 2-km buffer was a significant predictor of development probability, with a 10% increase in protected area increasing the odds of conversion by a factor of 1.20.

Discussion

For all three sites conservation actions were spatially clustered, tending to occur near previously protected sites. This finding provides support for the first component of the concept of leverage that argues that protected areas should spawn new protected areas nearby. Although the correlation on all three sites is in the direction hypothesized by this concept of leverage, it is difficult to infer exact causal pathways from our observational study. It is possible that conservation on one parcel encourages neighboring landowners to consider conserving their property. It may also be that many conservation organizations simply aim to protect areas that are well connected with other conserved areas (Noss 2003) and strive to create “corridors” of protected land between two larger protected parcels (cf. Hess & Fischer 2001). Differentiating between these two possibilities is beyond the scope of this paper and would require a survey of the motivation of landowners who decided to protect their land.

One apparent implication of the spatial clustering of conservation actions is that the geography of past conservation actions has a strong influence on future conservation patterns. For all three sites the large patches of protected habitat were in federal ownership by the 1940s. These big parcels appear to control where current conservation activities occur, and these activities are often thought of as extending or connecting these big parcels to form a coherent conservation network. This spatial clustering has positive and negative implications for the conservation of these landscapes. On the positive side current conservation activities appear to be well connected with other large conserved patches. This connectivity presumably brings benefits in terms of increasing wildlife movement, gene flow, and landscape integrity (e.g., Noss 2003). On the negative side most of the big conservation patches were acquired to protect water quality or forest resources and not biodiversity (Margules & Pressey 2000). If contemporary conservation actions are too concentrated near these big parcels, and big parcels happen not to occur near areas of importance for the preservation of biodiversity, then important areas may be left unprotected.

Table 1. Regression results for factors controlling land conversion in three areas in the United States.

Location and variable	*Deviance*	p	*Coefficient*	*SE*
Macon, Georgia[a]				
intercept	null model		1.94	0.41
housing density change in town	0.0	0.98	−0.000427	0.0013
slope	17.3	<0.001	−0.298	0.074
distance to stream/wetland	6.0	0.014	−0.102	0.046
distance to road	330.0	<0.001	−0.997	0.057
percent development in 4 km	1.7	0.19	−3.01	2.3
protected buffer in 2 km	17.8	<0.001	0.984	0.25
autocorrelation term	1599.2	<0.001	8.16	0.40
Quabbin, Massachusetts[b]				
intercept	null model		−5.93	0.907
housing density change in town	0.741	0.39	−0.0051	0.005
slope	2.41	0.12	0.224	0.15
distance to stream/wetland	6.98	0.008	0.341	0.134
distance to road	25.29	<0.001	−0.409	0.109
percent development in 125 m	13.449	<0.001	2.94	0.75
protected buffer in 4 km	1.517	0.22	0.846	0.68
autocorrelation term	1081	<0.001	18.18	0.876
Phoenix, Arizona[c]				
intercept	null model		−4.83	0.35
housing density change in town	2.17	0.14	−0.000339	0.00016
slope	11.6	<0.001	−0.358	0.073
distance to stream/wetland	0.42	0.52	−0.0995	0.034
distance to road	109.0	<0.001	−0.0808	0.045
percent development in 500 m	978.9	<0.001	6.78	0.24
protected buffer in 2 km	24.6	<0.001	1.83	0.24
autocorrelation term	20919	<0.001	13.6	0.26

[a] *Null deviance of a model with only an intercept term is 4699 on 5362 df, whereas the residual deviance of the final model is 2727 on 5355 df.*
[b] *Null deviance of a model with only an intercept term is 1909 on 5564 df, whereas the residual deviance of the final model is 778 on 5557 df.*
[c] *Null deviance of a model with only an intercept term is 25,560 on 26,140 df, whereas the residual deviance of the final model is 3,514 on 26,133 df.*

We found little support for the second component of leverage hypothesizing that the existence of protected lands has a mitigating effect on the rate of land conversion that occurs in nearby spots (cf. Armsworth et al. 2006). In all three sites the coefficient relating percent protected area in a buffer to the probability of conversion was not significantly less than zero. Indeed, at two sites the coefficient was significantly positive, implying that areas with more land protection had higher rates of conversion in the vicinity. This was not simply a matter of selecting the wrong scale for analysis. These analyses were attempted with a variety of neighborhood sizes, and the absence of any leverage effect appeared clear over distances from 0.125 to 4 km. Our results are consistent with recent work by Armsworth et al. (2006), which predicts, on the basis of economic models, that biodiversity conservation can create positive feedbacks in the land market, increasing development. They are also consistent with empirical analysis of the valuation of greenspace as reflected in real estate prices (Mansfield et al. 2005).

There was a clear temporal trend in all three sites, from the protection of large parcels in early time periods to smaller parcels in the last several decades. Although our observational study cannot precisely determine causation, this is likely due to increased parcelization, the further subdivision of property parcels into smaller and smaller pieces (Mehmood & Zhang 2001; Best 2002). This parcelization increases land prices (Wear et al. 1999), which makes land protection on large scales difficult. In a landscape that has become broken up into many small parcels, future land protection may have fewer opportunities and is likely to be very expensive per unit area conserved. Anything that increased the efficiency of private land conservation thus appears highly desirable. Unfortunately, although we found evidence that land protection tended to be associated with future land protection nearby, the presence of protected lands did not have an inhibitory effect on nearby land development; if anything, the opposite seemed true. Our finding of smaller and smaller land protection transactions may not apply to all land trusts because some are investing increasingly in larger conservation easements with stronger restrictions on subdivision (Kiesecker et al. 2007; Rissman et al. 2007).

More research is needed to fully understand the causal reasons for these trends, especially landowner and land-trust surveys to determine their reasons for undertaking particular actions. Nevertheless, a few tentative conclusions may be drawn from our study. Land-trust organizations should not expect their protection efforts to slow development. Indeed their efforts may even increase development pressure. They should, when possible, continue to cluster newly protected parcels near existing protected areas when possible, all else being equal (i.e., a site's biodiversity, cost, and threat).

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