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Protection status and proximity to public-private boundaries influence land use intensification near U.S. parks and protected areas

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Abstract

Public parks and protected areas are highly valued resources for recreation, education, and conservation of species and ecosystems. Increased demand for exurban lifestyles near protected areas may threaten these services, but to date research has been limited to case studies or considered only the most protected areas. We quantified changes (1990–2010) in the density of residential housing and impervious surface within 1, 10, 25, and 50 km of 6,644 U.S. protected areas, from highly protected national parks and wilderness areas to less protected game reserves and recreation areas. In almost all cases, housing density and impervious surface near protected areas were significantly higher than what would be expected by chance. Lands near protected areas with the highest level of protection (GAP I) experienced the greatest overall increase in housing and impervious area over time, but––contrary to earlier projections––little change occurred within 1 km of private-public boundaries. An opposite pattern occurred near the least protected areas (GAP IV)––lands immediately adjacent to these parks experienced the largest rates of change, but this growth decreased further from their boundaries. Most of the changes near GAP IV areas occurred in the Eastern Temperate Forest ecoregion, though the greatest overall rates of land change occurred in the Southwest. Our findings suggest that previous studies may overestimate the extent to which housing growth broadly threatens conservation of U.S. protected areas. For the first time, we demonstrate that land change near protected areas varies by protection status, proximity to public-private boundaries, and ecoregion. To make these data more accessible to practitioners, we have created an interactive, online mapping platform that allows anyone to explore location-specific trends in land change near parks and protected areas.

KEYWORDS

exurbanization, housing development, impervious surface, land change, USGS GAP

1 | INTRODUCTION

Parks and protected areas serve important functions for conserving valued species, habitats, and landscapes (Dudley & Stolton, 2010; Geldmann et al., 2013; Karanth, Nichols, Hines, Karanth, & Christensen, 2009; Taylor et al., 2011; Watson, Dudley, Segan, & Hockings, 2014); provisioning ecosystem services (Palomo, Martín-López, Potschin, Haines-Young, & Montes, 2013; Postel & Thompson Jr., 2005; Soares-Filho et al., 2010); providing clean drinking water (Dudley & Stolton, 2003); and supporting tourism-based economies (Thomas, Koontz, & Cornachione, 2018). However, the same natural, scenic, cultural, and recreational amenities that draw millions of visitors to parks and protected areas also attract rapid housing growth at their boundaries (Gimmi et al., 2011; Joppa, Loarie, & Pimm, 2008; Radeloff et al., 2010). Proximity to protected open space, such as parks, increases property values (Pejchar, Morgan, Caldwell, Palmer, & Daily, 2007), with the largest increases in value observed for homes adjacent to permanently protected natural areas (Irwin, 2002). This land use intensification threatens biodiversity (Vitousek, Mooney, Lubchenco, & Melillo, 1997) through habitat loss and fragmentation (Fahrig, 2003; Forman & Deblinger, 2000; Haddad et al., 2015) and spread of invasive species (Joly et al., 2011; Predick & Turner, 2008); water resources through pollution and changes to hydrology (Houlahan & Findlay, 2003; Pringle, 2001; Theobald, Goetz, Norman, & Jantz, 2009); and fire regimes through altered vegetation structure and management priorities (Schoennagel, Nelson, Theobald, Carnwath, & Chapman, 2009). In the United States, past land use trajectories suggest that the rapid intensification of land use will continue into the future (Radeloff et al., 2010), threatening the value of protected areas (Davis & Hansen, 2011; Shafer, 1999).

The U.S. relies on a network of protected areas that range from highly protected national parks and wilderness areas to less protected game reserves, scenic and recreation areas, and reservoirs to meet different conservation and societal needs. The USGS Gap Analysis Project (USGS GAP, 2016) defines federally designated protected areas by protection status (Table 1). To date, research on housing density has focused on only a selection of protection statuses. Most notably, Radeloff et al. (2010) examined housing development between 1940–2000 around U.S. wilderness areas, national parks, and national forests and concluded that land use trajectories threaten protected areas' conservation values. However, understanding land change around protected areas requires a comprehensive examination of all levels of protection. We hypothesize that different allowable uses and levels of protection may encourage different patterns of development near boundaries; the "pristine" scenic and natural amenities of highly protected GAP I areas may draw different levels of exurban development than the recreational opportunities of lower-status GAP IV areas.

To address this knowledge gap, we analyzed recent trends in land use change around the full spectrum of U.S. parks and protected areas by combining three publically available, nationwide data sets: National Land Cover Database (NLCD) (Homer et al., 2015), Protected Areas Database of the United States (PAD-US) (USGS GAP, 2016), and the U.S. Census. We examined (a) the extent to which lands adjacent to parks and protected areas have continued to attract both new residential housing development and impervious surface since Radeloff et al.'s (2010) analysis through the year 2000, (b) whether or not protection status influences rates of land change, and (c) which U.S. states and ecoregions are experiencing the most development near parks and protected areas. Answers to these questions are needed to understand how interconnections between public and private lands affect environmental change and to anticipate future changes in landscape connectivity in the context of a park's protection status. Exploration of trends in land change by ecoregion can help conservation scientists and practitioners prioritize vulnerable places for conservation planning and management resources.

Our analysis included over six thousand federally designated protected areas, nearly doubling the number and spatial coverage of protected areas examined by previous studies. We examined 25 land management designations (up from three in prior research) and considered all four levels of GAP protection status (Table 1). Past research has focused on housing growth and population as indirect measures of conservation impact near parks and protected areas. Here, we also analyzed changes in impervious surface, which captured additional dimensions of landscape changes from the construction of infrastructure accompanying housing and population growth, such as roads, parking lots and businesses/services. Impervious surface can impact ecosystem processes through direct mortality (Boarman & Sazaki, 2006), habitat fragmentation (Delaney, Riley, & Fisher, 2010), and erosion and sedimentation (Johnson et al., 2000).

In the past, it has also been difficult to quantify the extent to which parks and protected areas attract nearby development, although evidence suggests that they do through enhanced recreational and aesthetic amenities (Gimmi et al., 2011; Hammer, Stewart, Winkler, Radeloff, & Voss, 2004). Our analysis provides the first statistical inference of the "draw" of parks and protected areas: we compared development and impervious surface around these areas to a second set of protected areas that

TABLE 1 USGS Gap Analysis Program (GAP) protection statuses for federally designated protected areas within the conterminous United States

GAP status	Definition	Examples	Number of entities (% total)	Total area, km^2 (% total)
GAP I	Permanent protection from conversion of natural land cover and mandated management plan to maintain a natural state; disturbance events allowed to proceed without interference or mimicked through management.	Great Smoky Mountains (NC, TN), Yellowstone (WY, MT, ID), Yosemite (CA)	825 (12.4%)	231,176 (34.4%)
GAP II	Permanent protection from conversion of natural land cover and mandated management plan to maintain a primarily natural state; may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance.	Gauley River National Recreation Area (WV), Pisgah National Game Refuge (NC), Valley of the Gods (UT)	1,755 (26.4%)	134,537 (20%)
GAP III	Permanent protection from conversion of natural land cover for the majority of area; subject to extractive uses of broad, low-intensity (e.g., logging) or localized intense type (e.g., mining); confers protection to federally listed endangered and threatened species throughout the area.	Chimney Rock National Monument (CO), Mono Basin National Scenic Area (CA), Sheyenne National Grassland (ND)	3,582 (53.9%)	285,467 (42.4%)
GAP IV	No known institutional mandates or legally recognized easements. Managed primarily for recreation and cultural and historic purposes.	Allegheny Reservoir (NY), Oak Creek Canyon Recreation Area (AZ), Rainbow Falls Recreation Area (WA), Rock Creek Park (MD), W. Kerr Scott Reservoir (NC)	482 (7.3%)	21,702 (3.2%)

we randomly relocated within the conterminous U.S. To make these data and findings more accessible to practitioners, we have also created an interactive, online mapping platform that allows land managers, planners, and the public to explore location-specific trends in land change: go.ncsu.edu/land-change-near-us-parks-and-protected-areas.

2 | METHODS

2.1 | Protected areas and ecoregion data

The Protected Areas Database of the United States (PAD-US) is a comprehensive, national inventory of all public parks and protected open spaces managed by federal, state, district, and local government agencies (USGS GAP 2016). From the PADUS database (v. 1.4), we extracted 6,644 terrestrial parks and protected areas in the conterminous United States (CONUS) that are managed by five federal agencies (Bureau of Land Management, National Park Service, United States Forest Service, United States Fish and Wildlife Service, and United States Army Corps of Engineers) (Figure 1a). Each protected area is assigned one of four GAP statuses that define the level of mandated protection afforded to land and species within the area (Table 1). All four GAP statuses are represented at the federal level with permanent protections to land change in GAP I, II, and III. However, GAP IV designated areas have no known federal mandates for protection and are managed primarily for recreation (Table 1). Eighty-seven percent of GAP IV federally designated areas are recreation management areas and include recreation reservoirs managed by the U.S. Army Corps of Engineers and recreation areas managed by the USDA Forest Service. The remaining 13% include national monuments and memorials managed by the National Park Service and historic and archaeological sites managed by the USDA Forest Service (USGS-GAP, 2016). We summarized the geographical distribution of federal protected areas and the proportion of each GAP status occurring within each of the lower 48 states and 10 EPA Level

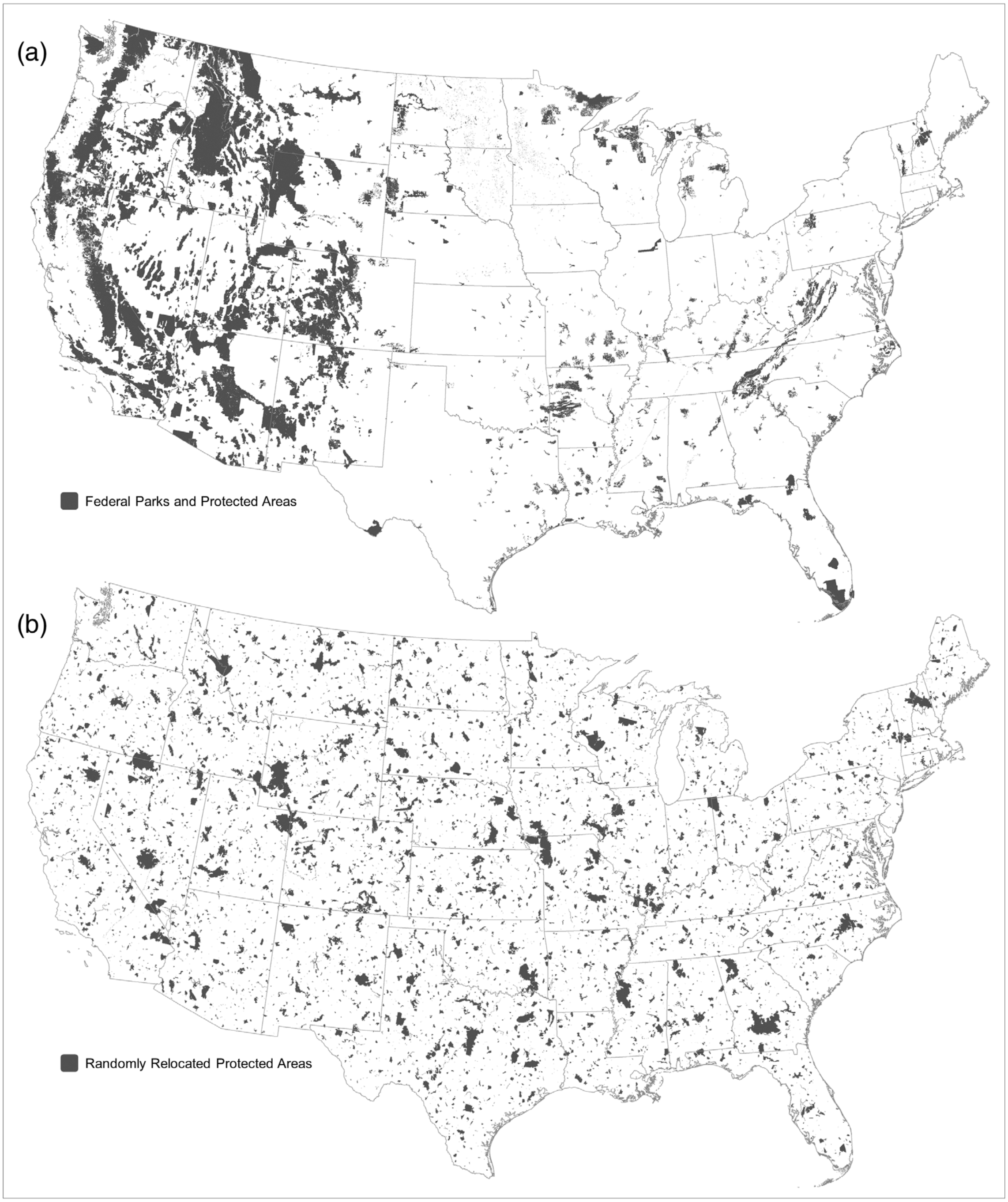

FIGURE 1 Distribution of (a) federally designated protected areas across the conterminous United States, and (b) protected areas randomly relocated

1 Ecoregions of the CONUS (Figure 2) (Omernik & Griffith, 2014; USEPA, 2010).

2.2 | Spatial analysis of development near protected areas

Using two independent datasets, we calculated decadal changes in mean housing density and mean percent impervious surface cover adjacent to federal protected areas at increasing radii of 1 km (0–1 km), 10 km (0–10 km), 25 km (0–25 km), and 50 km (0–50 km). We selected these radii to correspond to Radeloff et al. (2010) and to represent a range of ecological processes that occur across spatial scales, from local erosion and runoff (e.g., Johnson et al., 2000) to large-scale disruption of wildlife movement corridors (e.g., Mladenoff, Sickley, Haight, & Wydeven, 1995). We measured housing density (housing units per hectare) using block-group house count data from the 1990, 2000, and 2010 Censuses and

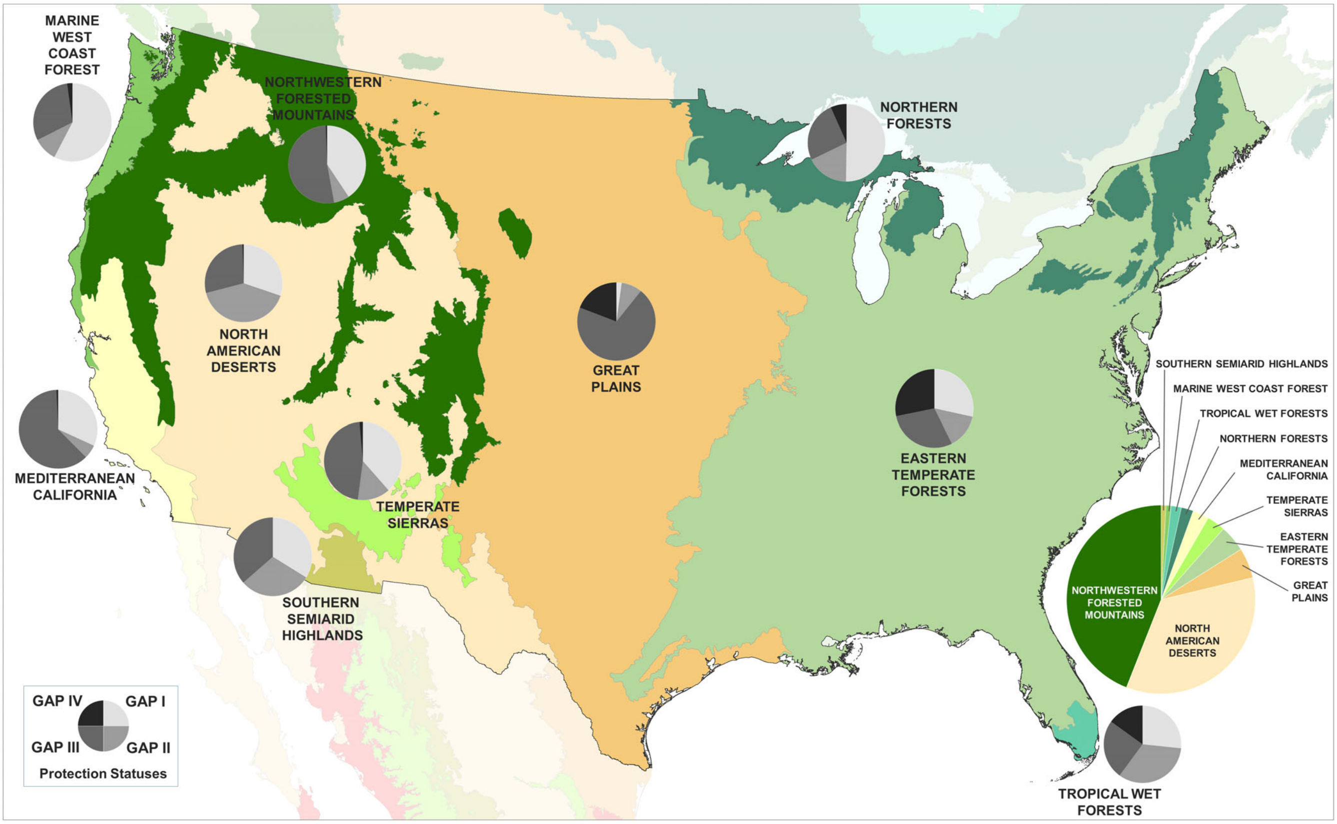

FIGURE 2 Proportional area of holdings by GAP protection status (gray charts) within each EPA Level 1 Ecoregion, and the relative share (color chart) of total federal protected area (total: 695,000km^2) within each ecoregion

mean percent impervious surface cover using the NLCD percent imperviousness data for 2001 (Homer et al., 2007) and 2011 (Xian et al., 2011). NLCD's imperviousness datasets provide standard, nationwide repeat-measures of the fraction of each pixel that is impervious surface. Next, we used R programming to produce a second set of non-overlapping randomly located protected areas (Figure 1b) that allowed us to test whether more development occurred adjacent to federal protected areas than expected by chance. We iteratively assigned each protected area a new centroid at a random location and emulated the boundary vertices around the centroid until all vertices were contained within the CONUS boundary. We then quantified changes in mean housing density and mean percent impervious surface cover adjacent to random protected areas using the same timesteps and increasing radii noted above. We avoided artificially deflating measurements of land change in the randomized areas by ignoring polygon fragments where randomized and actual protected areas overlapped with each other. We assume that housing development is either prohibited or very small in U.S. protected areas (Tanner, 2002).

Two computational challenges prevented running the randomization many times. First, over 200 hours of compute time is required to randomly locate the numerous non-overlapping polygons (6,644 protected areas) for each of the four radii and calculate housing density and impervious surface (30 h × 4 radii × 2 metrics for each random run). Second, the large size of the 25 and 50 km radii produces overlapping boundaries that cover the entire conterminous United States in every random realization. We conducted a sensitivity analysis for the 10 km radii to explore the extent to which results could be affected by a chance random distribution. We randomized the locations of the protected areas 10 times and calculated housing density and impervious surface for each random realization. Comparison of the means of each random realization using a non-parametric, Kruskal–Wallis test suggests no significant differences for housing density (Chi-square = 4,940.17, $p = .73$, df = 9) or impervious surface (Chi-square = 3,405.21, $p = .52$, df = 9) among the 10 randomized placements of protected areas.

2.3 | Statistical analysis of change

We used two-sample, Kolmogorov–Smirnov (K-S) tests in R to analyze the extent to which mean housing density and mean percent impervious surface differed between the observed and randomly relocated protected areas. These differences were analyzed at each distance radius for every timestep across the entire conterminous U.S. For both the observed and randomly relocated protected areas, we next analyzed differences in mean housing density and mean impervious surface between each of the four GAP protection statuses. The nonparametric K-S test compares the cumulative distribution of an empirical and a hypothetical (or random) dataset and makes no assumptions about the normality of the data (Massey, 1951).

We used the Friedman test (Daniel, 1990) to assess repeated measures of housing density between 1990, 2000, and 2010 within 1, 10, 25, and 50 km, of all parks and protected areas. The Friedman test is a non-parametric version of a one-way ANOVA with repeated measures on three or more occasions for the same subject (e.g., decadal changes in housing density near a protected area). The test is free from requirements of data being normally distributed and with equal variances. Where the Friedman test produced a significant result, we implemented a post-hoc test to identify significant differences between pairwise groups and the direction of effects. We used the non-parametric Wilcoxon signed-rank test to compare differences between percent impervious surface in 2000 and 2010 as this metric had only two measures. The Wilcoxon test compares two related samples or repeated measurements to assess paired differences when data lacks normal distribution.

We applied the Spearman's rank-order correlation, a non-parametric test for analyzing two non-normal variables, to measure the strength and direction of association between mean housing density and mean percent impervious surface for lands surrounding all protected areas at each radii and for lands adjacent to protected areas of each GAP status. Finally, we summarized the geographical distribution of changes in mean housing density and mean percent impervious surface by ecoregion and state.

3 | RESULTS

Nearly 695,000 km^2 of federally protected areas are distributed across the conterminous United States with permanent protections for land and species on nearly 97% of those lands (Figure 1a and Table 1). Approximately 80% (by area) of these protected areas occur in two ecoregions: the Northwestern Forested Mountains and the North America Deserts (Figure 2). The majority of protected areas in all ten ecoregions have GAP protection levels of I, II, and III (lower numbers indicate higher protection, Table 1). Ecoregions in the central and eastern U.S. have a greater proportion of GAP IV areas (e.g., 28.2% in the Eastern Temperate Forests) compared to the western U.S., where there are few or no (e.g., Southern Semiarid Highlands) GAP IV protected areas (Figure 2).

Mean housing density (1990, 2000, 2010) and percent impervious surface (2000, 2010) increased significantly over time within 1, 10, 25 and 50 km of all parks and protected areas in aggregate (Figure 3; $p < .001$ Friedman post-hoc tests—housing density change; $p < .001$ Wilcoxon signed-rank tests—percent impervious surface change). Housing density and impervious surface were highest on lands within 10 km of protected area boundaries for all years, but decreased beyond 10 km. In all cases, our observed measures of housing density and impervious surface near protected areas (Figure 1a) were significantly higher than lands near the randomly relocated protected areas (Figure 1b) (D = 0.04–0.44,

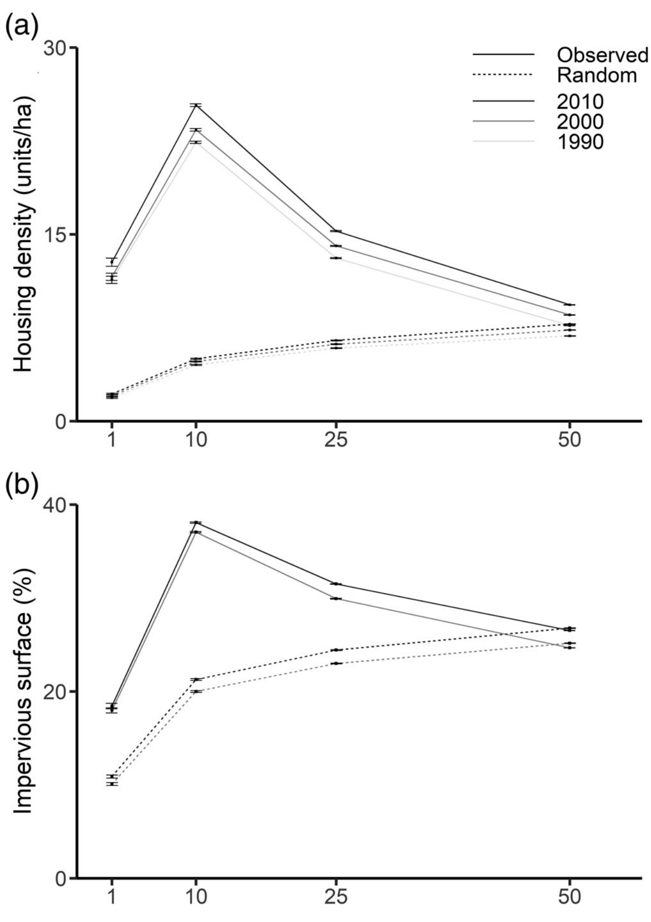

FIGURE 3 Distribution of (a) mean housing density in 1990, 2000, and 2010 and (b) mean percent impervious surface in 2000 and 2010 surrounding observed and randomly relocated protected areas across the conterminous United States at 1, 10, 25, and 50 km from protected area boundaries. Bars represent 95% confidence intervals. Data are aggregated across GAP I-IV protection status. Results for each GAP status are reported in Figure 4

$p < .001$ for housing density; $D = 0.037–0.32$, $p < .001$ for % impervious surface), except at 50 km for percent impervious surface, where random values were significantly higher than observed ($D = 0.03$, $p < .001$) (Figure 3). The largest differences between observed and random measures of housing density and impervious surface occurred at 10 km (Figure 3). For example, observed measures of housing density were five times larger than random (Figure 3a).

Patterns of housing density and impervious surface near parks and protected areas were significantly and positively correlated in aggregate ($r_s \geq 0.78$, $p < .001$ at each distance radii) and within each GAP protection level ($r_s \geq 0.7$, $p < .001$ for each GAP status). Housing density and percent impervious surface around GAP I, II, and III protected areas increased with distance from their boundaries, with impervious surface increasing on average 1.2 times faster than housing density with distance from GAP I, II, and III protected areas (Figure 4; Appendix S1). Though lands near protected areas with the highest level of protection (GAP I) experienced the greatest average percent increases in housing density (72%) and impervious surface (16%) over time, these metrics changed relatively little within 1 km of GAP I areas (29% and 9% increases). In contrast, lands immediately adjacent (< 1 km) to GAP IV areas experienced the greatest increases in housing and impervious surface ($p < .001$ Friedman post-hoc for housing density change; $p < .001$ Wilcoxon signed-rank for % impervious surface change), which progressively decreased at further distances (10–50 km) from their boundaries (Figure 4; Appendix S1). Furthermore, observed measures of housing density and percent impervious surface near GAP IV protected areas (1–10 km) were significantly greater than random ($D = 0.5$ and 0.5, $p < .001$ for housing density at 1 km and 10 km; $D = 0.5$ and 0.4, $p < .001$ for % impervious surface at 1 km and 10 km), whereas observed housing density and impervious surface on lands within 10 km of GAP I, II, and III protected areas were significantly lower than random ($D = 0.7–0.24$, $p < .001$ for housing density; $D = 0.14–0.2$, $p < .001$ for % impervious surface).

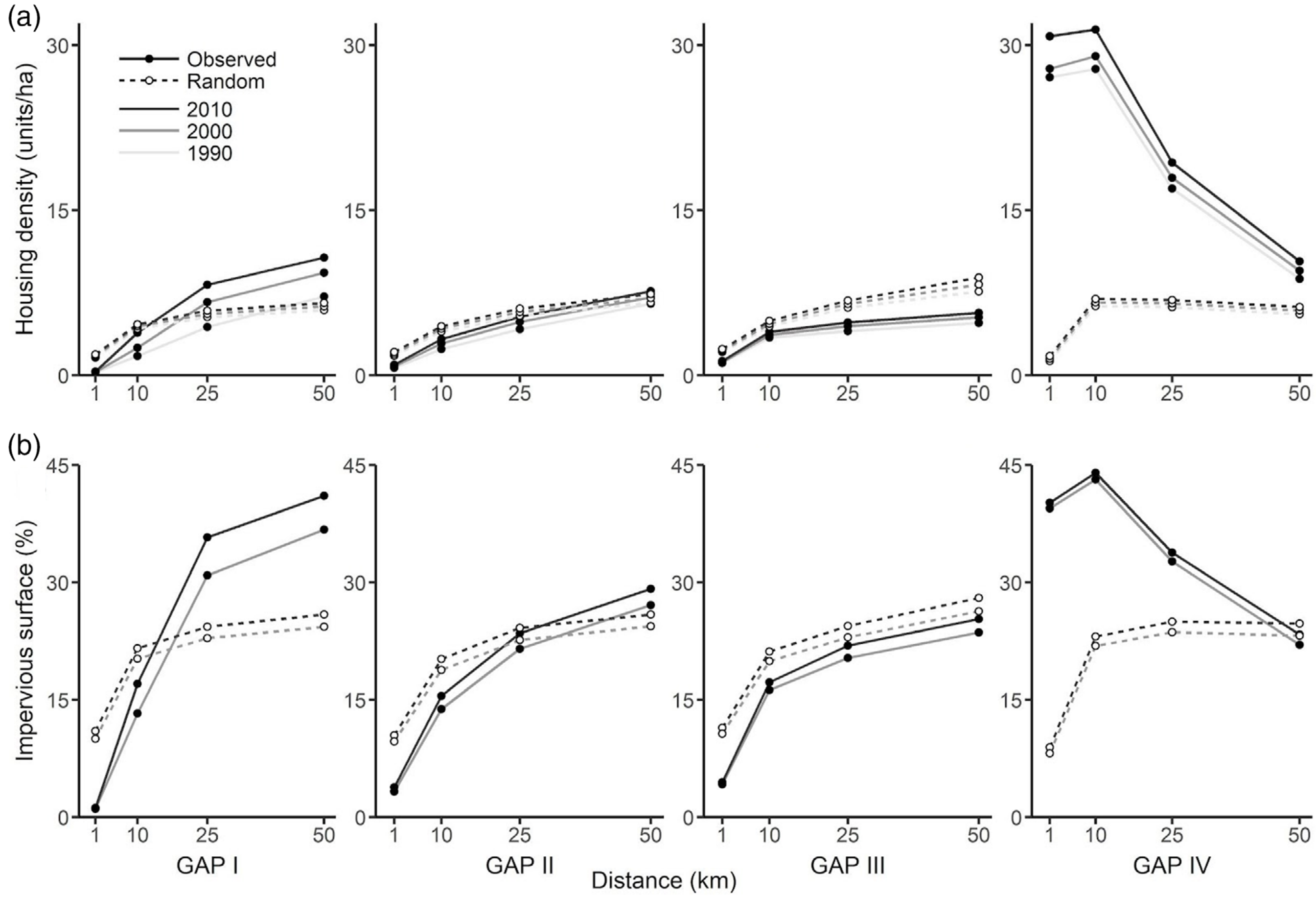

FIGURE 4 Distribution of (a) mean housing density in 1990, 2000, and 2010, and (b) mean percent impervious surface in 2000 and 2010 surrounding observed and randomly relocated protected areas by GAP Status (I, II, III, IV) and at 1, 10, 25, and 50 km from protected area boundaries (means and confidence intervals reported in Appendix S1)

Mean housing density and percent impervious surface within 10 km of protected areas increased in all ten ecoregions (Figure 5). Housing density was highest near protected areas in the Eastern Temperate Forests and Mediterranean California ecoregions (Figure 5a). The greatest rates of change in housing density occurred in the North American Deserts (66%), the Temperate Sierras (42%), and the Northwestern Forested Mountains (38%). The greatest rates of changes in impervious surface occurred in the Southern Semiarid Highlands ecoregion (23%) followed by the Temperate Sierras (18%) and North American Deserts (15%) (Figure 5b). Lands adjacent to protected areas of the Southern Semiarid Highlands had the lowest average proportion of impervious surface in 2000 (3%) and 2010 (3.7%), but exhibited the greatest rate of change among all ecoregions.

The highest mean housing densities within 10 km of GAP IV protected areas occurred in the Eastern Temperate Forest and Mediterranean California ecoregions (Appendix S2*A*), more than three times greater than housing densities surrounding GAP I, II, and III protected areas (Figure 6). The greatest rates of change in housing density within 10 km of GAP IV protected areas occurred in the Northwestern Forested Mountains (52.7%) ecoregion, followed by 43% increases in both the Temperate Sierras and Marine West Coast Forest ecoregions. Counter to overall trends, there was a 30% decrease in mean housing density within 10 km of GAP IV areas in the Tropical Wet Forests. Percent impervious surface was also greatest adjacent to GAP IV protected areas in the Eastern Temperate Forest and Mediterranean California ecoregions (Appendix S2*B*), though the greatest rates of change occurred in the Temperate Sierras (16.9%) and Great Plains (11.8%) ecoregions.

Mean housing density and percent impervious surface within 10 km of protected areas increased over time in almost every state of the conterminous U.S. (Appendix S3). Virginia, Maryland, and Massachusetts had the highest mean housing densities (Appendix S3A), whereas the greatest rates of change occurred in Nevada (216%), followed by Delaware (74%) and Texas (52%). These same three states also experienced the greatest rates of change in impervious surface (NV = 34%; DE = 20%; TX = 16%).

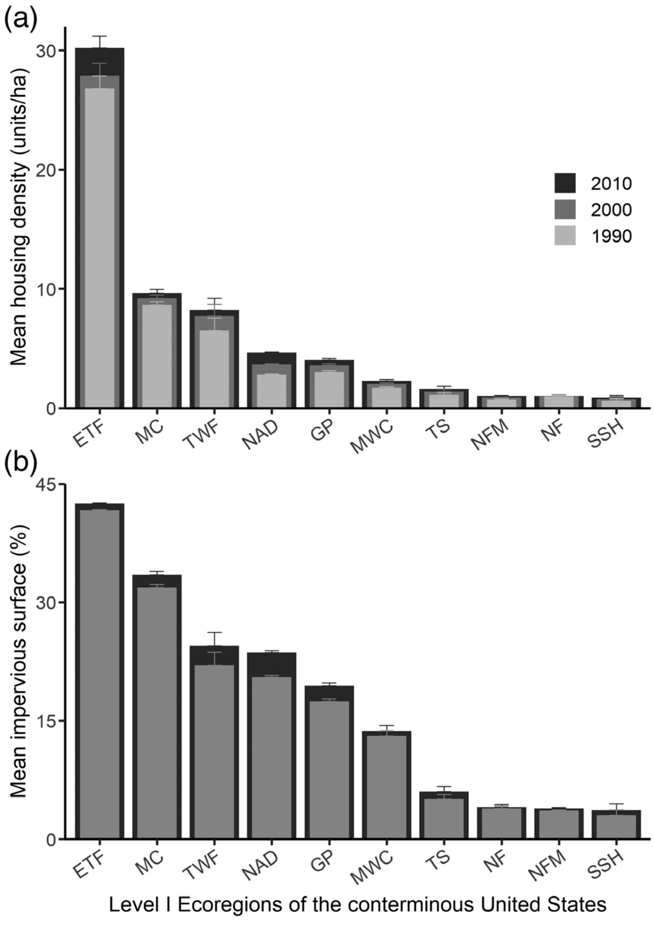

FIGURE 5 Distribution of (a) mean housing density in 1990, 2000, and 2010 and (b) mean percent impervious surface in 2000 and 2010 within a 10-km radius of protected areas and by EPA Level I Ecoregions. Bars represent 95% confidence intervals. ETF, Eastern Temperate Forests; GP, Great Plains; MC, Mediterranean California; MWC, Marine West Coast Forests; NAD, North American Deserts; NF, Northern Forests; NFM, Northwestern Forested Mountains; SSH, Southern Semiarid Highlands; TS, Temperate Sierras; and TWF, Tropical Wet Forests

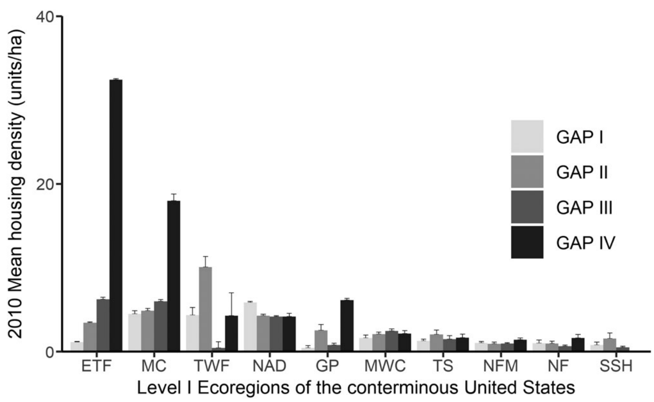

FIGURE 6 Distribution of 2010 mean housing density within a 10-km radius of the GAP status areas across EPA Level I Ecoregions of the conterminous United States. Bars represent 95% confidence intervals. ETF, Eastern Temperate Forests; GP, Great Plains; MC, Mediterranean California; MWC, Marine West Coast Forests; NAD, North American Deserts; NF, Northern Forests; NFM, Northwestern Forested Mountains; SSH, Southern Semiarid Highlands; TS, Temperate Sierras; and TWF, Tropical Wet Forests

4 | DISCUSSION

Parks and protected areas are valuable, and valued, for an array of conservation, recreation, aesthetic, and cultural services and benefits. The ability of parks to provide these services will depend in part on population growth, infrastructure, and demand for resources occurring on surrounding lands. Case studies covering smaller geographic areas (e.g., the Great Lakes [Gimmi et al., 2011]) and specific protection designations (e.g., National Parks (Davis & Hansen, 2011), National Wildlife Refuges [Hamilton et al., 2015]) support these concerns. To date, only one nation-scale study of threats from land use change (1940–2000) to a suite of federally protected areas in the U.S. has been conducted (Radeloff et al., 2010). Our research generally concurs with their seminal finding that housing densities have increased on lands adjacent to the parks and protected areas of the conterminous United States. However, we found land use change near parks and protected areas differed significantly with protection status inside the park and proximity to the protected area boundary.

First, our examination of land change (1990–2010) suggests that recent growth next to (<1 km) the most protected areas may be slower (+15% housing density per decade) than previously reported (+474% growth 1940–2000 or approximately +80% per decade) (Radeloff et al., 2010). This finding reflects current socio-economic drivers of exurbanization and land change and includes the complete set of GAP I protected areas. Nevertheless, our findings do quantitatively support the conclusion that natural and cultural amenities of parks and protected areas are, and continue to be, draws for development. We statistically compared development around protected areas with control areas of the same size and geometry, randomly distributed across the conterminous United States, and found that housing density and impervious surface were higher around parks and protected areas than would be expected by chance (Figure 3) and are increasing over time. Population growth and associated infrastructure development is happening across much of the country, but comparisons with randomly distributed areas allowed us to better understand the "pull" of parks and protected areas.

Amounts of development, though, are not consistent at all distances from protected area boundaries, but rather peak at 10 km, suggesting that recent trends differ from earlier projections. Radeloff et al. (2010) found that wilderness areas had the highest housing growth rates in their immediate vicinity (< 1 km) and that between 1970–2000, national forests had the greatest growth within and immediately adjacent to protected area boundaries. We found that housing density overall is both greatest and increasing most rapidly within 10 km from park boundaries. The percent impervious surface metric mirrors these findings, with change accelerating over time in lands within 10 to 50 km of protected area boundaries. This result lends quantitative support to the "one-hour rule" described by amenity migrants (Hansen et al., 2005) who want to live within a one-hour drive of the recreational and aesthetic amenities they value. Taken together, our results suggest that when considering potential impacts, monitoring, management, and planning efforts focused on development right at park boundaries (< 1 km) may miss important impacts 10–50 km away. These *near-park* effects could significantly compromise the ability of protected areas to provide important ecological and social values. Road networks needed to support housing development can produce cumulative impacts on animal populations (Boarman & Sazaki, 2006), which may be undetectable in some taxa for decades (Findlay & Bourdages, 2000). Traffic noise negatively affects breeding densities of some passerine birds (Peris & Pescador, 2004), and large wildlife, including wolves (Mladenoff et al., 1995) and mountain lions (Forman et al., 2003), only thrive where road density is less than 0.6 km/km^2. Housing development can lead to accelerated depletion of water resources in water-limited systems, with increasing number of wells and greater depth to groundwater (Vukomanovic, Doumas, Osterkamp, & Orr, 2013). In-migration can impact nearby communities by creating conflict between long-term residents and newcomers (Walker & Fortmann, 2003) or between growing local communities and broader regional interests (Steinberg & Clark, 1999). Gateway and amenity communities near some public lands face a variety of problems associated with rapid growth, such as lack of affordable housing, income inequality, and transportation issues (Rumore, Stoker, Levine, & Romaniello, 2019).

Second, examining land change trends relative to protection status allowed us to compare the threats of human encroachment around the "most protected" and "least protected" parks. Our results indicate that there are different housing development patterns around protected areas with different protection (GAP) statuses. Paradoxically, GAP I protected areas (with the highest level of protection and restriction on management and extractive activities) are among the most at-risk from land use intensification and human encroachment. We found that GAP I protected areas have higher housing densities and faster rates of change than GAP II or III protected areas at 10–50 km from park boundaries. While management and extractive activities around GAP II and GAP III protected areas (Table 1) can degrade landscapes and compromise scenic values, the "pristine" natural amenities of GAP I protected areas are likely more desirable for residents, explaining their higher nearby housing densities and percent impervious surface.

We found that increases in housing density 1990–2010 were greatest at 10–50 km from GAP I protected area boundaries, with smaller increases at 1 km. The differences between these and earlier findings (Radeloff et al., 2010) may be attributable, in part, to the fact that we considered all GAP I protected areas; our analysis examined housing density surrounding over six thousand parks and protected areas, covering the entire range of terrestrial, federally-listed protected areas and all levels of GAP protection status. Lands near GAP I areas also experienced the greatest percent increases in impervious surface over time within 10–25 km of protected area boundaries, and their average percent impervious surface at 25 km was higher than all other protected areas (Figure 4). Given the mandate of GAP I protected areas to provide permanent protection and maintain a natural state, this rapid growth around the nation's "most protected" areas means ever-growing risk of these natural icons becoming vulnerable islands in an asphalt sea.

In contrast to GAP I, we found that GAP IV protected areas, which are federally designated but have no known institutional mandates restricting activity, have a greater percentage of impervious surface and higher housing density in their immediate vicinity (< 1 km), but experienced less development further from park boundaries (Figure 4). Our geographical summaries show that most GAP IV areas are located in the eastern United States, where there is much less public land overall, than in the West (Figure 6). GAP IV protected areas represent important recreational and scenic amenities accessible on public lands, and these trends suggest that the amenities and lower use restrictions of GAP IV protected areas are a draw for housing development and associated infrastructure. Overall, a small number and proportion of protected areas are in GAP IV status (Table 1), but these parks heavily influence the overall trends in housing density and impervious surface (Figures 3 and 4). The immense growth around eastern GAP IV protected areas suggests that these public resources are meeting important societal needs. Where continued development puts these resources at risk, attention and management resources should be dedicated to better understanding the unique growth around GAP IV protected areas. In assessing drivers, impacts, and trends, it is common practice to examine by agency or use types (e.g., National Parks (Davis & Hansen, 2011), reservoirs (McKean, Johnson, Taylor, & Johnson, 2005), BLM lands [Dombeck, 1996]); our results suggest that there is merit in considering these questions by protection status.

Third, we summarized the geography of land change near protected areas by both ecoregion and state. This perspective highlights the unique challenges faced by the "least protected" (GAP IV) areas from rapid residential development in the eastern United States. Although they have not experienced the fastest growth, Eastern Temperate Forests protected areas started at higher values of housing density and percent impervious surface and have continued to grow. Protected areas such as Valley Forge National Historical Park, Lake Lanier Reservoir, Minnesota Valley National Wildlife Preserve, Rock Creek Park, and Indiana Dunes National Park are now essentially embedded within the suburbs of Philadelphia, Atlanta, Minneapolis, Washington, D.C., and Chicago, respectively.

The most rapid growth in housing density (1990–2010) has taken place in the North American Desert (NAD), Temperate Sierras (TS), Northwestern Forested Mountain (NFM) and Southern Semiarid Highland (SSH) ecoregions of the western US. The NAD ecoregion in particular, which includes the rapidly growing Arizona Sun Corridor (Phoenix-Mesa-Scottsdale metro area and Tucson) and the Las Vegas-Henderson-Paradise (NV), Salt Lake City (UT), Albuquerque (NM), and Boise City (ID) metropolitan areas has experienced the most rapid development around parks and protected areas (Figures 2 and 5). Some of the population growth propelling development around protected areas stems from amenity migration, where natural features and lifestyle drivers include scenic beauty (Gosnell & Abrams, 2011; Waltert & Schläpfer, 2010), expansive vistas (Vukomanovic & Orr, 2014), recreational opportunities (Hansen et al., 2005; Marcoullier, Clendenning, & Kedzior, 2002) and climate (McGranahan, 2008).

In addition to the houses themselves, low-density residential development leads to the building of new road networks and other impervious surface. By adding percent impervious surface as a metric of development to our analyses, we captured the full footprint of infrastructure near protected areas. Across ecoregions, increase in impervious surface is greatest for the NAD, while the NFM has not added much impervious surface around protected areas. Increases in impervious surface, particularly road networks, can affect a host of ecosystem processes through direct mortality (Boarman & Sazaki, 2006), habitat fragmentation (Delaney et al., 2010) and disruption of wildlife movement corridors (Shepard, Kuhns, Dreslik, & Phillips, 2008), traffic disturbance (Shannon, Angeloni, Wittemyer, Fristrup, & Crooks, 2014), and erosion and sedimentation (Johnson et al., 2000). These effects can be amplified in non-forested landscapes (Forman, Reineking, & Hersperger, 2002), such as those found in the NAD, suggesting that protected areas within this ecoregion are increasingly vulnerable.

Our results show that lands surrounding parks and protected areas are a draw for development, putting these valuable public goods at risk. We also found that housing density and percent impervious surface vary with increasing distance from public-private boundaries, suggesting that these fine-scale land use trends should be incorporated into future land use projections. Regional land change models that incorporate these spatially explicit draws of parks and protected areas can situate these trends in a regional context and shed light on the potential implications of the "near-park" effects identified here. Accelerating development around parks and protected areas has led to calls for conservation planning at landscape scales that extend beyond park boundaries (DeFries, Hansen, Newton, & Hansen, 2005; Gimmi et al., 2011). Our findings provide additional guidance on the spatial extent of those landscape perspectives and how they differ depending on protection status.

Land use intensification, demand for resources, and sustainable protected areas management are immense multifaceted problems that will take concerted, coordinated efforts across multiple levels of government, industry (e.g., tourism), NGOs and citizen groups to address. The results we present here strengthen our foundational understanding of patterns and trends of housing development and impervious surface and provide (eco)regional context. Participatory research approaches that involve diverse groups of stakeholders can inform landscape and regional planning by highlighting spatial interactions and the interacting spatial scales of decision-making and economic, cultural, and environmental drivers (Vukomanovic, Skrip, & Meentemeyer, 2019). With this starting point, interested parties from across these sectors can explore the trends reported here through our interactive, online mapping platform [go.ncsu.edu/land-change-near-us-parks-and-protected-areas]. This platform provides visualization of dynamic processes, which can serve as a focus for discussion around communal landscapes that are personally valuable and where shared connections can advance cooperation and learning.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

J.V and R.K.M conceived the study. J.V., K.K.S., J.B.V. and R.K.M. contributed to study design. K.K.S. and J.B.V. performed the spatial analyses. J.V. wrote the original draft. J.V., K.K.S., J.B.V. and R.K.M. contributed to the preparation of the final manuscript.

ETHICAL STATEMENT

No ethics approval was required for this research.

DATA ACCESSIBILITY STATEMENT

The data used are publicly downloadable from the referenced sources, and available via the interactive mapping platform at: https://go.ncsu.edu/land-change-near-us-parks-and-protected-areas. The code used to query the data and perform the analyses is available at: https://github.com/ncsu-landchangelab/land-change-near-us-parks-and-protected-areas.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of this article.

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