Housing growth in and near United States protected areas limits their conservation value

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Protected areas are crucial for biodiversity conservation because they provide safe havens for species threatened by land-use change and resulting habitat loss. However, protected areas are only effective when they stop habitat loss within their boundaries, and are connected via corridors to other wild areas. The effectiveness of protected areas is threatened by development; however, the extent of this threat is unknown. We compiled spatially-detailed housing growth data from 1940 to 2030, and quantified growth for each wilderness area, national park, and national forest in the conterminous United States. Our findings show that housing development in the United States may severely limit the ability of protected areas to function as a modern "Noah's Ark." Between 1940 and 2000, 28 million housing units were built within 50 km of protected areas, and 940,000 were built within national forests. Housing growth rates during the 1990s within 1 km of protected areas (20% per decade) outpaced the national average (13%). If long-term trends continue, another 17 million housing units will be built within 50 km of protected areas by 2030 (1 million within 1 km), greatly diminishing their conservation value. US protected areas are increasingly isolated, housing development in their surroundings is decreasing their effective size, and national forests are even threatened by habitat loss within their administrative boundaries. Protected areas in the United States are thus threatened similarly to those in developing countries. However, housing growth poses the main threat to protected areas in the United States whereas deforestation is the main threat in developing countries.

conservation threats | effectiveness | parks | reserves

Protected areas are crucial for the conservation of species threatened by land-use change and habitat loss (1–4). However, the effectiveness of protected areas depends on their ability to stop habitat loss within their boundaries (5), and on their connections to other wild areas via corridors and semiwild areas in their surroundings (6). In developing countries, some protected areas have failed even to limit internal habitat loss (7, 8), and deforestation in their surroundings has isolated protected areas and reduced the effective size of available habitat (9–11). In developed nations, where conservation policies and institutions are generally stronger, internal habitat loss is assumed to be minimal, but protected areas may be isolated because of increasing land-use intensity in surrounding areas (12). Further, though deforestation is a good indicator of conservation effectiveness among protected areas in tropical forests, other indicators are needed in nonforested environments, and for developed nations, where forest cover is generally increasing. In the United States, rural sprawl poses a major conservation threat (13–15), suggesting that housing growth may be a better indicator of threat to protected areas (16).

Our research goal was to estimate housing growth in and near US protected areas since 1940, and to project future growth up to 2030. We examined long-term housing growth trends in the conterminous United States, not short-term fluctuations in housing markets. On average, housing has grown by 13 million units per decade (20.8% growth) since 1940. The 1970s witnessed the highest growth (19.5 million new housing units, 28.6%), as well as the "rural renaissance" when nonmetropolitan housing growth outpaced metropolitan growth for the first time in US history (17). Homebuyers are drawn to natural amenities (15). This, coupled with increasing willingness to commute long distances, mobility at retirement age, and telecommuting, has allowed people to move to the countryside. Seasonal homes (i.e., cabins) are increasing, and the Baby Boomer generation has begun retiring to "the woods" (18). The combined effect of these trends has been strong housing growth in areas that are accessible from metropolitan centers but close to forests and other wildlands (14).

Strong rural housing growth in the United States raises conservation concerns. Housing development and accompanying road development fragments native habitat (15), fosters exotic species invasions (19), and increases predation by mesopredators and pets (20). The environmental effects of a house can reach far beyond its immediate site (21), leading to biodiversity declines (22) and biotic homogenization (23). Thus, housing growth both within protected areas (i.e., on private inholdings) and in their immediate vicinity has direct negative effects.

Housing growth in the surroundings of protected areas is also detrimental in that it reduces the total area of habitat, severs corridors to other wild areas, and can interrupt disturbance processes, such as fire, that maintain native habitat. Corridors are critical because protected areas are often small (24) and sited on less-productive land (25), and their biodiversity may depend on surpluses from surrounding areas (13). Thus housing growth both within and near protected areas must be quantified to fully assess conservation threats resulting from development.

Protected areas have a long history in the United States, and different types of protected areas offer different levels of protection. The United States created the world's first national park, Yellowstone, in 1872, the first national forest in 1891, and the first federally protected wilderness areas in 1964. Wilderness areas enjoy the highest level of protection, and are managed to remain "untrammeled by man" (IUCN Protected Area category Ib) (26). National parks are managed primarily for ecosystem protection and recreation (IUCN category II). By contrast, national forests are managed for sustainable use and are afforded the least protection (IUCN's category VI). Wilderness areas encompass 191,000 km^2, national parks 103,000 km^2, and national forests 869,000 km^2. We examined wilderness areas, national parks, and

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national forests to capture the full range of protection afforded to federally protected areas, and their different threats. All three types of protected areas can be threatened by adjacent housing growth. National forests are also threatened by development within their administrative boundaries due to private inholdings. Inholdings are much less common in wilderness areas and national parks, although they do occur.

We analyzed housing development in and near protected areas from 1940 to 2030 across the conterminous United States. Housing data were derived from the 2000 US Decennial Census, which is a complete enumeration of all housing units. The decennial census also reports the year in which a housing unit was built for a sample of 17% of all housing units. We used this information to estimate historic housing densities for each decade since 1940 by partial block group (average size 2.45 km^2; see *Methods* and refs. 15 and 27). Future housing densities to 2030 were projected based on 1990s housing growth rates, and controlled to county-level population projections (see *Methods*). The spatial dataset generated for this study constitutes the most detailed long-term housing estimates and projections available for the conterminous United States.

Decadal housing data were summarized within the administrative boundaries of national forests, and within 1, 5, 10, 25, and 50 km of each wilderness area, national park, and national forest. This range of distances was chosen to capture different threats. Administrative boundaries of protected areas delineate the lands subject to management plans and actions, but not all lands within administrative boundaries are publicly owned. Housing units within administrative boundaries and within 1 km exert a direct influence on protected areas (e.g., habitat loss, noise and light pollution, and increased predation from pets) (21). At greater distances, housing contributes to the isolation of protected areas, disruption of connective corridors, and introduction and spread of invasive species. Even as far as 50 km from the protected area, housing growth increases recreational activity within the protected areas, because residents are typically within a 1-h drive.

Results

Housing Growth near Protected Areas. Wilderness areas enjoy the highest level of protection, but that does not limit development in their surroundings. In 2000, 20.5 million housing units were within 50 km of a designated wilderness area (18% of all housing units in the conterminous United States), compared with only 4.4 million (12%) in 1940 (Fig. 1). Wilderness areas also exhibited the highest housing growth rates in their immediate vicinity (Fig. 2). The number of housing units within 1 km of a wilderness area grew from 9,400 in 1940 to 54,000 in 2000 (474% growth).

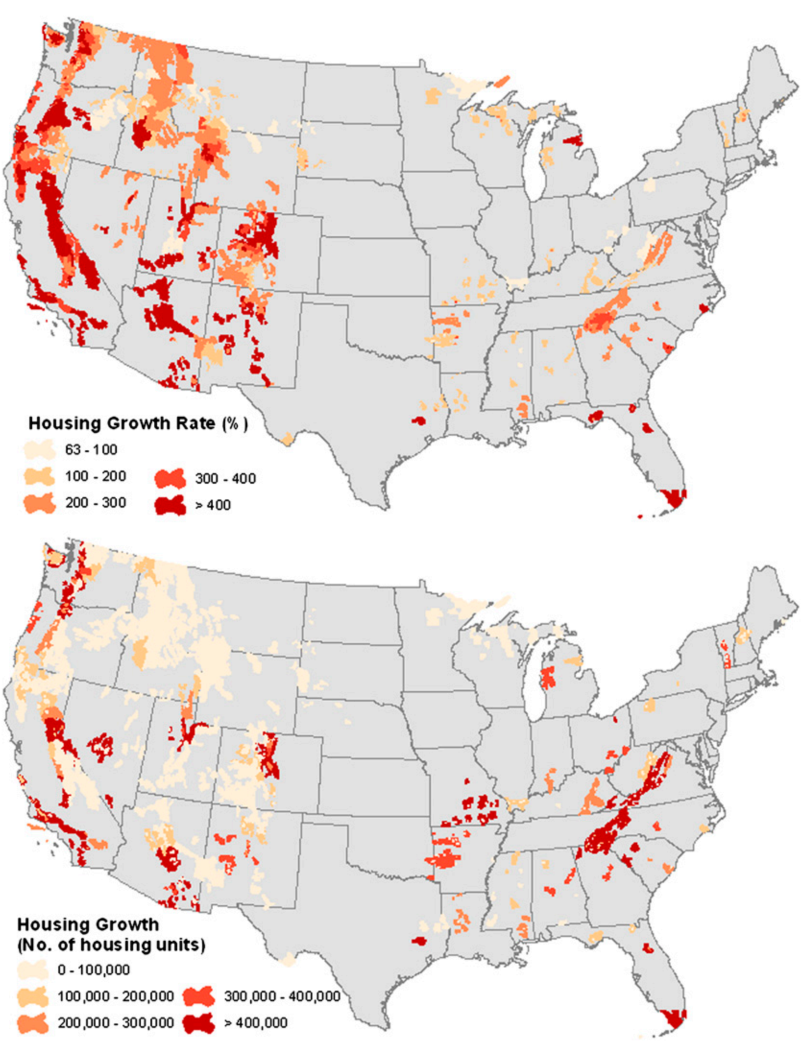

Fig. 1. Housing growth rates (*Upper*) and absolute housing growth (*Lower*) from 1940 to 2000 within 50 km of each wilderness area, national park, and national forest in the conterminous United States.

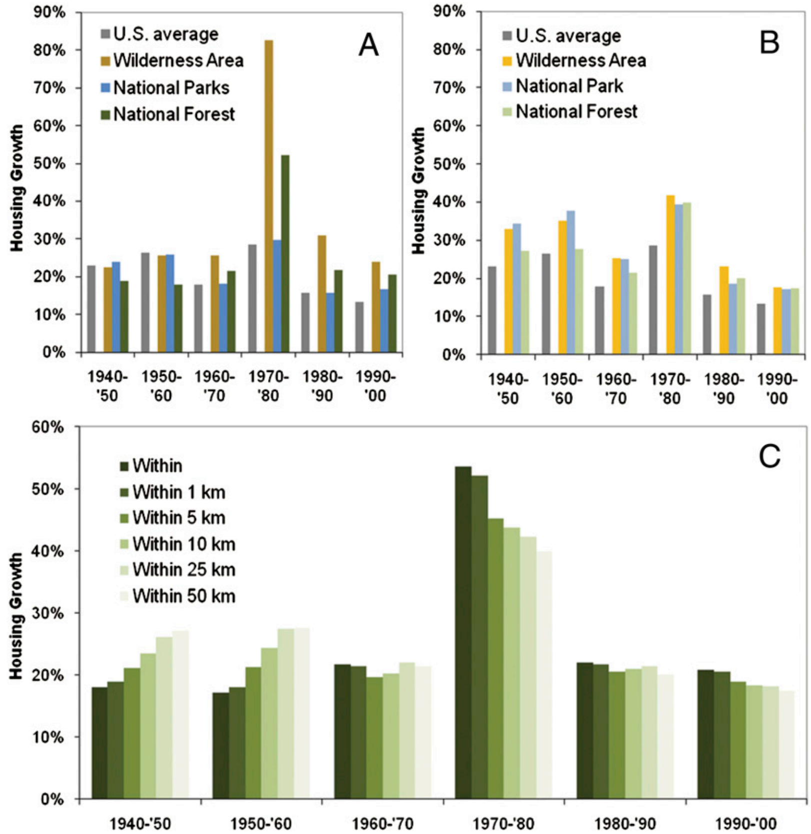

Fig. 2. Decadal housing growth rates (1940–2030) (*A*) within 1 km of all wilderness areas, national parks, and national forests, (*B*) within 50 km of all wilderness areas, national parks, and national forests, and (*C*) within national forests.

However, the absolute number of housing units remained comparatively low within 1 km of wilderness areas, because wilderness areas are commonly embedded within other public lands, which limit development.

In 1940, national parks exhibited the lowest number of housing units within 50 km (1.5 million). However, by 2000 this number had grown by 5.1 million, to 6.6 million, and there were 85,000 housing units within 1 km of national parks. National parks in the eastern United States had a particularly high absolute number of housing units in their surroundings (Figs. 1 and 3*B*), but growth rates were highest in the West (Fig. 1), in part because western housing densities were very low in the 1940s.

National forests experienced the highest absolute housing growth in their vicinity. Between 1940 and 2000, the number of units within 50 km of national forests grew from 9.0 million to 34.8 million (rising from 24% of all housing units in the coterminous United States in 1940 to 30% in 2000). Similarly the number of housing units within 1 km of a national forest increased from only 484,000 in 1940 to 1.8 million (Figs. 1 and 2).

Over the past 60 years, housing growth rates at different distances from national forests were very similar (280% and 289% within 1 and 50 km, respectively), and all exceeded the national average (209%). Lands within 50 km of national forests underwent the fastest growth in the 1940s and 1950s (27% both decades; Fig. 2), whereas growth within 1 km (18%) lagged behind the national average during those two decades (23% and 26%). However, in the 1970s, areas within 1 km of national forests exhibited an all-time high 52% growth, and remained the fastest growing areas among all of the distances examined through the 1990s.

Housing Growth Within National Forests. The strong housing growth rates observed near protected areas raise the specter of substantially altered ecosystems disconnected from other wild places and incapable of protecting sensitive plant and animal species. However, development within protected areas may have even greater consequences. This phenomenon is mainly a problem for national forests, because they contain substantial private inholdings. In total, the number of housing units within national forests rose from 335,000 to 1,278,000 between 1940 and 2000, and housing density increased from 0.4 to 1.5 housing units/km^2. National forests in the eastern United States exhibited the highest housing growth rates within their boundaries. The reason for this is historical; eastern national forests were established on previously privately owned lands, whereas western national forests were created mostly from the public domain.

Housing growth within national forests exhibited a marked temporal trend. In the 1940s and 1950s, housing growth within national forests was less than 20% per decade, well below the national average (Fig. 2). However, in the 1970s, housing growth within national forests exceeded 50%, far outpacing the national average. Though growth rates within national forests have declined since then, they continue to exceed the national average. During the 1990s alone, 221,000 housing units were built within national forests. These growth trends emphasize that land within the administrative boundaries of national forests is prized real estate.

Future Housing Growth in and near Protected Areas. Perhaps the most important value of historic housing growth estimates is what they indicate about the future. Society can do little to alter existing development patterns, but policies could redirect future growth. Future housing growth depends in part on future economic conditions. Recent economic changes in the United States have highlighted the vulnerability of housing markets to cyclical variations and larger economic trends. However, housing growth

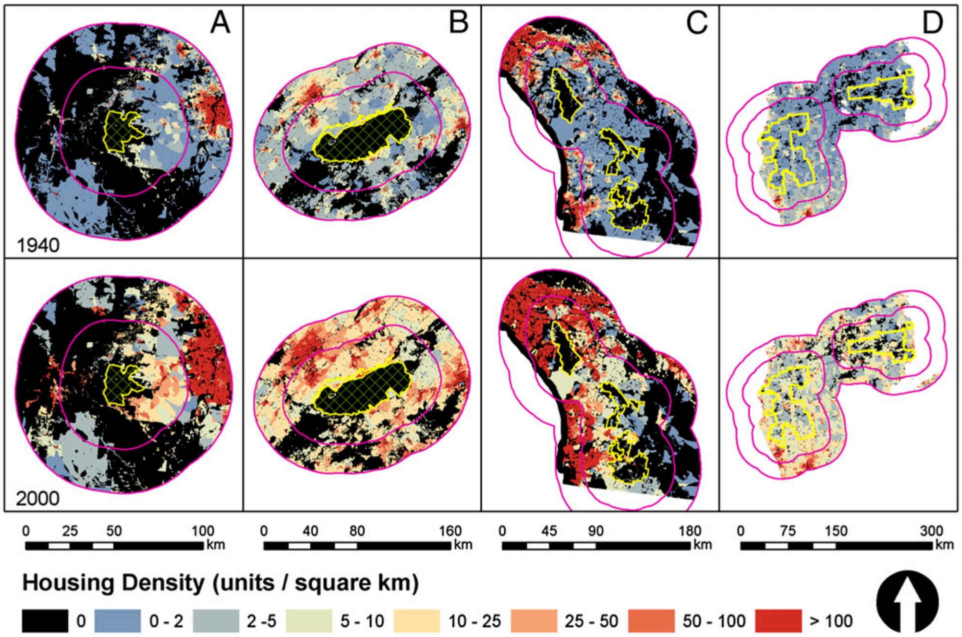

Fig. 3. Housing density in 1940 and 2000 within 25 and 50 km of (*A*) the Mount Evans Wilderness Area (Colorado, west of Denver), (*B*) Great Smoky Mountains National Park (Tennessee and North Carolina), (*C*) the Cleveland National Forest (California, south of Los Angeles), and (*D*) the Huron-Manistee National Forest (Michigan).

has been substantial in every decade we studied, and even the strong current downturn in the housing market may not fundamentally change long-term growth trends.

Future housing growth in and near protected areas will depend on housing demand and homeowner preferences. We based our estimates of overall housing growth rates on county-level population projections, translated population into housing units based on local 2000 household sizes, and used 1990s housing growth patterns to allocate new development spatially (see *Methods*). According to our projection, 16 million new housing units will be constructed between 2000 and 2010. The Census Bureau's intercensal housing estimates suggest that 12 million new housing units have already been constructed between 2000 and 2007 (http://www.census.gov/popest/housing/). Thus, despite the current economic downturn, at least three-quarters of the 16 million housing units we project by 2010 have already been constructed.

We project that the United States will reach 157 million housing units by 2030 (14%, 11%, and 8% growth in the 2000s, 2010s, and 2020s, respectively). If past spatial patterns continue, this will result in substantial numbers of new housing units in and near protected areas. For wilderness areas, we project 10 million additional housing units within 50 km by 2030 (45% growth 2000–2030); for national parks, 3 million new units (45% growth); and for national forests, 16 million new units (46% growth). Surrounding all three types of protected areas together, we predict a total of 17 million additional housing units within 50 km by 2030. The number of housing units within 1 km of protected areas will increase even more [88,000, 118,000, and 2,800,000 by 2030 for wilderness areas, national parks, and national forests, respectively (64%, 40%, and 52% growth)]. Housing within national forests will also rise substantially, with 662,000 new housing units, and reach a total of 1,940,000 by 2030.

Discussion

Our primary finding was that protected areas in the United States, one of the world's most developed nations, are threatened by housing growth. This threat is similar to that posed by resource extraction and land use change to protected areas in developing nations (7–11), albeit due to a different process (housing growth versus deforestation). In the United States, housing growth over the past 60 years has changed protected areas and their surroundings markedly, and projected future growth will exacerbate these changes. Protected areas attract development, and land protection displaces development to surrounding areas (11). Future development may even be stronger in and near protected areas than our projections suggest, as Baby Boomers retire, more roads are built, and faster communication allows further separation of homes and work places. The potential ecological consequences of these housing trends are substantial.

Protected areas in the United States are portrayed as a modern "Noah's Ark," offering safe havens for biodiversity (4). The housing growth rates in and near protected areas can threaten their conservation function: new houses will remove and fragment habitat, diminish water quality, foster the spread of invasive species, and decrease biodiversity (14, 23). However, ecological consequences will differ by locale and will also depend on the spatial patterns of growth. We selected four protected areas to highlight the different patterns and ecological consequence of housing growth (Fig. 3). The Mount Evans Wilderness Area in Colorado is a prime example of pressures from increasing recreational use. This wilderness area is affected by the strong growth of Denver's suburbs and exurbs (Fig. 3*A*). As a result, the Forest Service had to implement a mandatory permit system in 2005 to balance wilderness area preservation goals "against the pressures of growing populations and increased use" (28). Furthermore, the Colorado Division of Wildlife altered hunting regulations on Mount Evans to limit hunter access to white-tailed ptarmigan (*Lagopus leucura*) after substantial population declines during the 1980s (29). Fortunately, the Mount Evans Wilderness Area is connected to other public lands further west. In contrast, Great Smoky Mountains National Park (Fig. 3*B*) has witnessed strong housing growth in its surroundings in almost all directions. Air pollution now places Great Smoky Mountains National Park among the top five most polluted national parks in the United States (30), and poaching threatens native plants such as wild ginseng (*Panux quinquefolius*).

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Increasing isolation due to housing growth is also a problem in California's Cleveland National Forest (Fig. 3*C*). Housing growth has severed corridors and limited the dispersal of large carnivores such as cougars (*Puma concolor*) (6). Rising housing densities are also increasing wildfires; people start virtually all of the fires in southern California, and areas with higher housing density experience more fires (31). Fire frequencies now exceed what ecosystems can tolerate, and this has caused the replacement of coastal sage scrub by exotic invasive grasses (32). The spatial patterns of housing growth on the Cleveland National Forest are typical for most western national forests. Housing growth has been strong in the outskirts of the forest but limited within its administrative boundaries, where 76% of the land is owned by the Forest Service (90% for all western national forests).

The Huron-Manistee National Forest in Michigan (Fig. 3*D*), however, owns only 52% of the land within its administrative boundaries (55% for all eastern national forests). Widespread inholdings permitted considerable housing growth within the administrative boundaries of the Huron-Manistee. Fire regimes here are also affected by housing density, but here the fire frequency is now far below the historic range of variability (33); fires are suppressed because of the risk they pose to people and houses. The lack of fires has limited habitat availability for Kirtland's warbler (*Dendrocia kirtlandii*), a federally listed endangered species. Kirtland's warbler nests in young Jack Pine (*Pinus banksiana*) forests that typically regenerate on former burns (34). Moreover, human settlements have increased warbler nest parasitism from brown-headed cowbirds (*Molothrus ater*), and depressed warbler reproductive success (35). Thus, housing growth in and around protected areas is often associated with multiple impacts, and these interactions can amplify conservation threats (22).

These four case studies underscore the seriousness of ecological threats arising from housing encroachment on protected areas. Housing growth is not a natural disaster; it is a social process to which every citizen contributes. Future housing patterns will be determined by society—by policies, land use plans, zoning ordinance, and consumer choices. We conducted our analysis at the national scale to heighten the relevance of our work for policy makers, and to provide datasets and findings from our work for land managers and conservationists throughout the country. Minimizing and mitigating development threats will require actions at many levels: individual home- and landowners, local and regional government, land trusts and conservation groups, and federal agencies. Individuals can choose where and how to build, and they can limit the environmental impact of existing homes. Landscaping with native plants, keeping pets inside or leashed, limiting light and noise pollution, and avoiding lawn fertilizers that cause eutrophication of lakes and streams all help to keep nearby wild areas healthy.

Local and state governments are the major agents of land-use planning in the United States. Clustering new development, protecting important natural corridors from housing growth, and preventing development near ecologically sensitive areas are all measures that can minimize the effects of future development (36). Nongovernmental institutions such as land trusts and conservation easements can offer tax benefits to landowners in exchange for limiting future development, and help planners, communities, and homeowners understand their role in the larger ecological landscape (37).

Federal policies also affect future development patterns. If the goal is to minimize future housing growth in and near protected areas, then one effective approach is to purchase or swap for inholdings. Some such programs are in place, but funding must keep pace with rising land values so that opportunities can be realized. For example, large contiguous tracts of forest recently became available for purchase as the timber industry divested substantial portions of its land holdings (38), offering a chance to acquire additional public lands, often in close proximity to existing protected areas.

Our study shows that housing growth in and near US protected areas has been strong for 6 decades, and that lands near protected areas are attractive for development. If development continues unabated, it will further limit the conservation value of protected areas, and biodiversity will be impoverished. Management tools and land-use policies exist to ameliorate development threats, but historic housing growth suggests that these tools have either not been implemented or have not been successful in redirecting housing growth away from protected areas. Stronger efforts focusing on housing development within and near protected areas are needed if the conservation benefits of protected areas are to be enjoyed by future generations.

Methods

Housing Backcasts. All of our housing data were derived from the 2000 US Decennial Census, which provides a full enumeration of all housing units in the United States. Housing units include permanent residences, seasonal houses, and vacant units. A single structure with multiple apartments is counted as multiple housing units. The 2000 Census also provides an estimate of the year in which a housing unit was built, for a sample of all houses. On average, 1 in 6 houses was sampled, but sampling rates were much higher in areas with few houses to ensure accurate estimates. Sampling rates were one in two for governmental areas (counties, towns, townships, and school districts) with fewer than 800 occupied housing units (fewer than about 2,100 people), and one in four for governmental areas with 800–1,200 occupied housing units (about 2,100–3,100 people) (39). Unfortunately, the 2000 Census provides only the mean estimate for each reporting unit; no variance estimate is released, and that precludes the estimation of standard errors and confidence intervals. However, the total sample size was 18,345,474 housing units, which ensures robust results. We used this sample to "backcast" housing density for every decade before 2000 starting in 1940. These backcasts were adjusted to historic county-level housing totals to account for historic housing units no longer present in 2000. For a detailed description of the housing density backcast method, see ref. 27.

Housing Projections. The 1990s housing growth rates were used to project future housing growth. We applied the 1990s growth in decadal time steps to estimate housing density up to 2030. For each decade, the housing units were totaled by county, and adjusted to county-level housing projections. The county-level housing projections were derived from the 2008 Woods and Poole county forecasts (http://www.woodsandpoole.com/). Woods and Poole data are derived from an advanced demographic model and provide the most reliable population forecasts available. We converted population forecasts first into number of households using county-specific household sizes. Second, we converted number of households into the number of housing units, using county-specific vacancy rates. In areas with abundant seasonal homes, the majority of housing units may be vacant, and our translation of population size into housing density accounted for this. The county housing-unit totals from our projections were then adjusted to match those from the Woods and Poole-based housing estimates, and the adjustments apportioned back to partial block groups proportionally.

Census Data Geometry. We analyzed all housing density data at the partial block group level. Partial block groups are the smallest reporting unit for which the US Census Bureau releases information on the year in which a housing unit was built (27). However, the US Census Bureau does not provide spatial boundaries for partial blocks groups. We generated these by aggregating the smaller census blocks (for which no data on the age of housing units is released). The size of partial block groups varies, and is larger in rural areas and smaller in urban areas. The average size was 2.45 km^2. Partial block groups are on average almost an order of magnitude smaller than block groups, the spatial units for which housing density change is more commonly analyzed.

Public Lands. The boundaries of the partial block groups were further refined to account for public land. We used data from version 4.5 of the Protected Area Database (PAD) released in January 2009 by the Conservation Biology Institute (Corvallis, Oregon) to account for public lands. The PAD includes federal, state, and local public lands, and is the most detailed spatial dataset of public land ownership available in the United States. We compared the PAD with public land ownership for areas where we had worked previously (Wisconsin), and with a national ownership dataset provided by the Forest

Service, and found the PAD to be highly reliable. If a partial block group was partially within public land ownership, we assumed that the houses in this partial block group were located in the portion of the partial block group that is outside the public land. Hence our estimates of housing units within protected areas are conservative, because some may occur on land mapped as public. However, if a partial block group was entirely on public land, then we did not (re)move any housing units, and assumed that they were located on an inholding too small to be mapped as private land by the PAD.

The PAD also provided the boundaries for national parks and wilderness areas. For national forests, we used the administrative boundaries provided by the National Atlas (http://www.nationalatlas.gov/), because the PAD provided only the actual ownership boundaries. Among the National Park Service holdings, we limited our analysis to national parks, because other types of protected areas managed by the US National Park Service (e.g., national scenic rivers, national lakeshores, or national monuments) have different conservation status, and may not be managed for conservation goals. Similarly, we restricted our analysis to national forests, and excluded other areas (e.g., national grasslands) managed by the US Forest Service. Wilderness areas represented all federally designated wilderness areas irrespective of which land management agency (e.g., Forest Service, Park Service, Bureau of Land Management) is responsible for their management.

Housing Summary Statistics. We applied 1-, 5-, 10-, 25-, and 50-km buffers to the outer boundaries of the protected areas to calculate the number of housing units in the vicinity of protected areas. Summarizing housing densities for these buffers minimized the problem that no variance estimates were available for partial block groups, because any errors in the mean estimates due to sampling within a given partial block group would cancel each other out. These buffers were first applied individually to calculate the number of housing units in the vicinity of each protected area. Many wilderness areas are embedded in a national forest, or national park, and similarly, many national forests are adjacent to each other. This did not change our buffer analysis at the individual level. Second, we applied buffers to all protected areas of one type (e.g., wilderness areas) together. This was necessary to calculate the total number of housing units, for example, within 50 km of all wilderness areas. Adding the values from the individual calculations would have resulted in an overestimate, because some housing units are located within the buffers of two wilderness areas and would have been counted twice. Last, we calculated the number of housing units in the vicinity of all protected areas jointly.

For national forests only, we also calculated the number of housing units within their administrative boundaries. Private inholdings are very common in national forests, especially in the eastern United States, which is why we added this analysis. We did not calculate housing units within wilderness areas and national parks, although we know anecdotally that some occur. However, their number is generally very small, and the Park Service has removed many houses after establishing parks, which would have confounded our historical analysis.

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