

The extent of buildings in wildland vegetation of the conterminous U.S. and the potential for conservation in and near National Forest private inholdings

Amanda R. Carlson^{a,b,*}, Volker C. Radeloff^a, David P. Helmers^a, Miranda H. Mockrin^c, Todd J. Hawbaker^b, Anna Pidgeon^a

^a SILVIS Lab, Department of Forest and Wildlife Ecology, University of Wisconsin-Madison, 1630 Linden Drive, Madison WI 53706, USA

^b U.S. Geological Survey, Geosciences and Environmental Change Science Center, Lakewood, CO, USA

^c U.S. Department of Agriculture, Forest Service, Northern Research Station, Baltimore, MD, USA

HIGHLIGHTS

- We assessed proximity to buildings for wildland vegetation in the conterminous U.S.
- Nearly 1/3 of wildland vegetation is within 500 m of buildings.
- National Forest lands contain many areas near buildings on private inholdings.
- ~10% of National Forest lands could be affected by future development on inholdings.
- National Forest inholdings are opportunity areas for conservation.

ABSTRACT

Development in natural areas is a leading threat to biodiversity. Global conservationists have called for the expansion of protected areas to preserve wildlands that are free from buildings, and in the U.S., the 'America the Beautiful' initiative aims to protect 30% of land and water areas by 2030 (known as the '30x30' target). Here, we determined opportunities and limitations for conservation in the conterminous U.S. by assessing the extent of buildings in wildland vegetation. We focused specifically on National Forest lands, as these contain numerous private inholdings where development may occur. Using a newly available building footprint dataset, we determined 1) whether buildings were present and 2) numbers of buildings within three distances of wildland vegetation (100, 250, and 500 m), representing varying magnitudes of ecological impact. Our findings revealed that 29% of wildland vegetation nationwide was within 500 m of a building, 15% was within 250 m, and 5% was within 100 m. National Forest lands were less affected by building disturbance, but a substantial proportion (12%) of wildland vegetation area was within 500 m of a building. Of National Forest lands that were within 500 m of an inholding, 76% was not yet in proximity to a building; consequently, ~10% of National Forest lands (143,474 km²) are susceptible to impacts from future development on inholdings. We conclude that National Forest inholdings are therefore important opportunity areas for 30x30 conservation goals. Our assessments can inform where conservation efforts can limit impacts from present and future development on biodiversity.

1. Introduction

Housing growth and other development presents a major challenge for conservation (McDonald, Kareiva, & Forman, 2008; Watson et al., 2016; Wittemyer, Elsen, Bean, Burton, & Brashares, 2008). One factor driving this growth around the globe is an increasing desire to live near natural amenities (Cadieux & Hurley, 2011), as natural areas provide numerous physical and mental health benefits (McDonald et al., 2009).

However, the presence of buildings within or near natural areas can greatly alter ecosystems and degrade species' habitats, thereby causing declines in native biodiversity (McKinney, 2006) while aiding the spread of exotic species (Gavier-Pizarro, Radeloff, Stewart, Huebner, & Keuler, 2010; Luck, 2007). Furthermore, buildings and associated infrastructure (e.g., roads and powerlines) curtail animal migration, wildlife dispersal, and breeding success (Fischer & Lindenmayer, 2007), while human presence can substantially alter animal behavior (Finney, Pearce-

* Corresponding author at: U.S. Geological Survey, Geosciences and Environmental Change Science Center, Box 25046, DFC, MS 980, Denver, CO 80225, USA.
E-mail addresses: arcarlson@usgs.gov (A.R. Carlson), radeloff@wisc.edu (V.C. Radeloff), helmers@wisc.edu (D.P. Helmers), miranda.h.mockrin@usda.gov (M.H. Mockrin), tjhawbaker@usgs.gov (T.J. Hawbaker), apidgeon@wisc.edu (A. Pidgeon).

<https://doi.org/10.1016/j.landurbplan.2023.104810>

Received 23 December 2022; Received in revised form 17 April 2023; Accepted 19 May 2023

Available online 24 May 2023

0169-2046/Published by Elsevier B.V.

Higgins, & Yalden, 2005; Gaynor, Hohnowski, Carter, & Brashares, 2018). Protected areas are important for preserving natural areas that are free from the influences of buildings (Gaston, Jackson, Cantú-Salazar, & Cruz-Piñón, 2008), but the conservation value of protected areas is diminished by the presence of buildings within or near their borders (Hansen et al., 2011; Radeloff et al., 2010; Schulze et al., 2018).

Buildings can negatively impact surrounding natural areas in numerous ways (Bar-Massada, Radeloff, & Stewart, 2014), most notably through noise and light pollution (Buxton et al., 2017; Ciach & Fröhlich, 2017), conflicts between wildlife, humans, and pets (Loss, Will, & Marra, 2013; Madden, 2004), subsidized food and water sources (Fedriani, Fuller, & Sauvajot, 2001), invasive species introductions (Gavier-Pizarro et al., 2010; McKinney, 2006), traffic (Jaeger et al., 2005; van der Ree, Jaeger, van der Grift, & Clevenger, 2011), and human-caused changes to natural disturbance regimes, especially wildfires (Radeloff et al., 2018; Fig. 1). Effects of low-density housing are often observed within at least 500 m, with measurable changes in species composition (Gagné & Fahrig, 2010), invasive species abundance (Gavier-Pizarro et al., 2010), and wildfire ignition probability (Cochrane, 2001). Other types of development, such as oil and gas wells, also create disturbance up to ca. 500 m due to noise pollution (Francis, Paritsis, Ortega, & Cruz, 2011).

The magnitude and nature of ecological effect depends on both the distance from buildings and the number of buildings in proximity to natural areas, which also typically correlates with densities of associated infrastructure such as roads (Theobald, Miller, & Hobbs, 1997). For example, changes in species composition and behavior are most frequently observed within ca. 200 m of a building for birds and small mammals (Glennon & Kretser, 2013; Odell & Knight, 2001), but larger-bodied mammals may exhibit avoidance of buildings over ranges up to several kilometers (Benítez-López, Alkemade, & Verweij, 2010). Furthermore, higher building densities within a given distance have greater impacts on biodiversity (Pidgion et al., 2014; Wood et al., 2014) and are correlated with greater impacts from associated infrastructure

such as roads (Hawbaker, Radeloff, Hammer, & Clayton, 2005). Therefore, quantifying both the area in proximity to any building footprints, as well as the number of buildings within a given distance are effective metrics for assessing potential ecological impacts of buildings.

Conservation organizations have called for global efforts to expand protected areas to combat a multitude of environmental threats, including development and climate change. For example, the Global Biodiversity Framework calls for the protection of at least 30% of global land and ocean areas by 2030 (known as the '30 × 30' target; Milner-Gulland et al., 2021; Waldron et al., 2020). The United States officially adopted this target in 2021 as part of its 'America the Beautiful' initiative via executive order by the Biden administration (Exec. Order 14008: Tackling the Climate Crisis at Home and Abroad, 2021). The initiative calls on federal management agencies to identify target areas for expanding protected areas, or else taking other locally-led conservation actions to conserve natural resources and biodiversity, increase access to outdoor recreation, and support local control of resources (U.S. Department of the Interior, 2021). These goals have the potential to effectively limit the extent and/or the intensity of development pressures in natural areas and to create partnerships to improve access to resources in existing communities. However, deciding where to prioritize conservation efforts is a significant challenge. Systematic conservation planning aims to increase the representation of biodiversity in protected areas, with regard for how development may impact their effectiveness in maintaining viable populations (Margules & Pressey, 2000). Increasingly, future development trajectories are also considered to identify areas where populations may face increasing impacts (Carter et al., 2014). Given the increasing rate of human encroachment on the natural world, effective conservation depends on assessing the present extent and intensity of development in wildlands.

Many global protected areas are affected by development on private lands within their borders (de la Fuente et al., 2020). U.S. National Forest lands in particular are highly fragmented by inholdings (Stein et al., 2007), and as a result, many areas containing critical habitat or

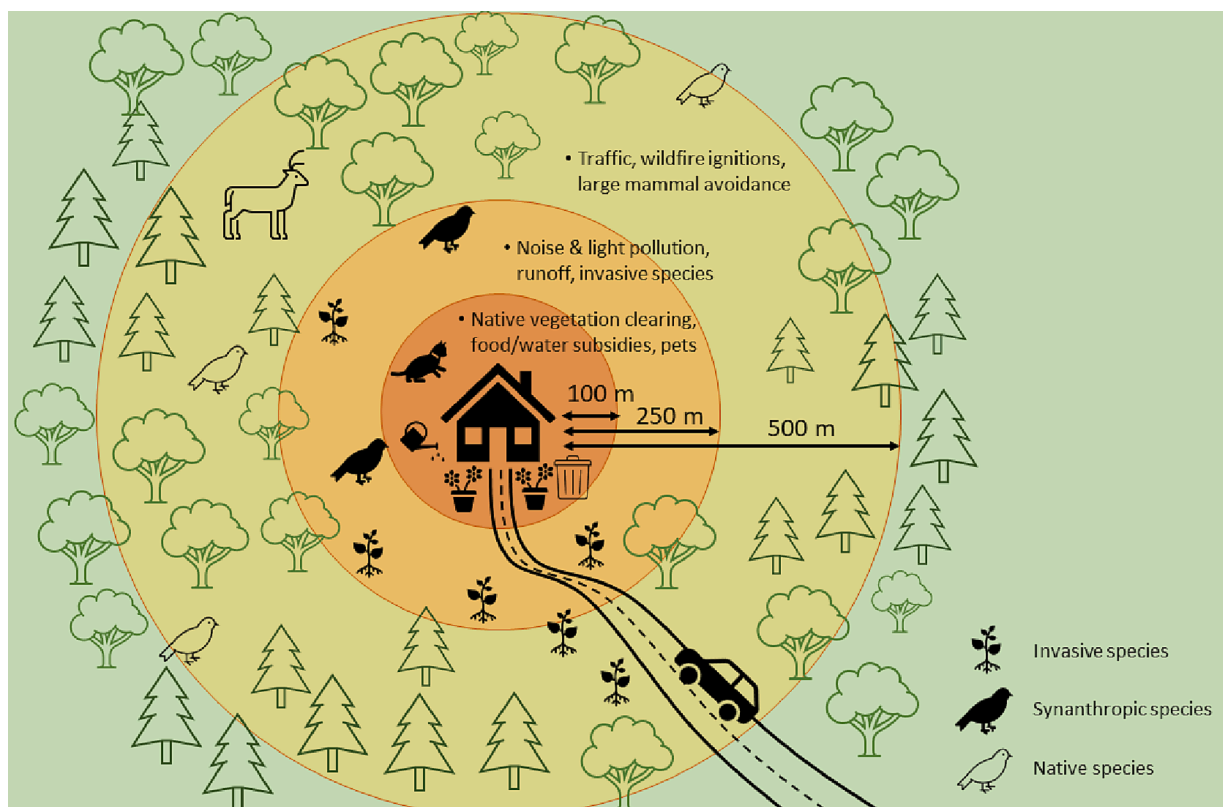


Fig. 1. Conceptual diagram illustrating the major impacts from buildings on wildlands within three ecological effect distances: 100 m, 250 m, and 500 m.

key ecological values can be affected by buildings. National Forests have faced impacts from rapid housing growth in the form of low-density, or ‘exurban’ development since the 1970s (Reisig et al., 2021; Wade & Theobald, 2010), and rates of housing growth in and near National Forests exceed the national average both in proximity to forest edges and within their borders on private inholdings (Mockrin, Helmers, Martinuzzi, Hawbaker, & Radeloff, 2022). Potential for future development on inholdings therefore threatens the ecological integrity of National Forest lands. Determining where natural areas may be affected by future development can help to identify opportunities for conservation, especially in National Forests and protected areas that are similarly fragmented by private lands.

Mapping individual buildings in wildland vegetation is challenging across large extents, and there is currently no assessment of the extent to which wildland vegetation in the U.S. in general or in protected areas is impacted. Prior work has focused on defining the wildland-urban interface (WUI), or the area where housing intermingles with or is adjacent to wildland vegetation. In this context, ‘wildland’ vegetation may include highly managed landscapes (e.g., grazed rangelands or logged forests), as vegetation near buildings is unlikely to be unmanaged wilderness. Approximately one-third of houses in the U.S. are in the WUI (Radeloff et al., 2005), indicating that housing has a substantial effect on wildland areas. However, WUI maps have limited use for identifying areas of conservation potential because they focus exclusively on identifying housing areas that are in proximity to wildland vegetation based on definitions designed to assess wildfire risk to houses. This definition includes a minimum housing density threshold to select areas where substantial populations face risk (Kramer, Mockrin, Alexandre, Stewart, & Radeloff, 2018). Here, we focus on identifying where wildland areas are in proximity to buildings, including industrial, commercial, and farm buildings, to identify areas where habitat quality and ecosystems are potentially impacted by human activity.

In this study, we assessed proximity to buildings in wildland vegetation of the conterminous U.S. and explored the use of our assessments for identifying conservation opportunities to meet 30 × 30 targets. Our aims were to 1) create a publicly available dataset representing proximity to buildings for wildland vegetation of the conterminous U.S., 2) quantify distance to buildings and numbers of buildings in wildland vegetation for the entire conterminous U.S., and 3) assess building impacts specifically on National Forest lands and their private inholdings. While these data can be used assess impacts of buildings on ecological values in myriad ways in various land types, we chose to focus our analysis on National Forest inholdings because rapid rates of development in these areas suggests there is a limited window of opportunity for conservation.

2. Methods

2.1. Study area

Wildland vegetation of the conterminous United States is dominated by temperate broadleaf forests in most of the East, coniferous forests in the Southeast and mountain West, temperate grasslands and agriculture in the central U.S., and desert shrublands and grasslands in the lowland West (Yang et al., 2018). The National Forest System is divided into eight Regions corresponding to these regional differences in vegetation type, and we used these to summarize geographic patterns in building presence in wildland vegetation. Federal protected areas, including National Forests (in addition to national parks and wildlife reserves) are most extensive in the western U.S., due to the fact that Euro-American settlement occurred later there than in the East. National Forests in the eastern U.S. include substantial private inholding areas because many of these forests were established following the Weeks Act of 1911, which allowed forest boundaries to be drawn around existing settlements by purchasing private lands that were largely unsuitable for development (Tidwell, 2011). Western National Forests are generally

more contiguous, but also contain private lands. For example, parcels owned by railroad are commonly arranged in a fragmented “checkerboard” pattern that often creates issues of access for recreation and forest management (Nie & Miller, 2010).

2.2. Data

We used Microsoft’s freely available building footprints dataset (available at <https://github.com/microsoft/USBuildingFootprints>; accessed January 2019), which provides footprints of 124,828,547 individual buildings in the conterminous U.S. The dataset was created by classifying high-resolution satellite images (0.3 m-resolution) using the EfficientNet semantic segmentation algorithm (Tan & Le, 2019), a high-efficiency convolutional neural network (Bing Maps Team, 2018). Imagery acquisition dates vary, with an average year of ca. 2012. Reported accuracies of the classifications are 93.5% recall and 99.3% precision, based on 5 million training images. For computational efficiency, we converted building footprints to point locations by calculating the centroid of each footprint.

Wildland vegetation data were derived from the 2016 National Land Cover Database (NLCD; Yang et al., 2018), which represents vegetation conditions near the collection dates of imagery used to develop the buildings dataset. The NLCD provides a continuous land cover classification for the U.S. at 30-m resolution. We selected all natural vegetation classes (deciduous, evergreen, and mixed forest, shrub/scrub, grassland/herbaceous, and woody and emergent wetlands) and combined these into a single wildland vegetation class. The NLCD does not separately classify vegetation with substantial management (e.g., plantation forests and grazed pastures), and therefore we use the term “wildland vegetation” inclusively to refer to any natural or semi-natural vegetation cover. We additionally summarized building extent and intensity in forests, shrublands, grasslands, and wetlands, combining deciduous, evergreen, and mixed forest into a single “forest” class and woody and emergent wetland classes into a single “wetland” class.

We obtained National Forest administrative boundary data from the USFS Geospatial Data Clearinghouse (available at <https://data.fs.usda.gov/geodata/>; accessed January 2021). These data represent the proclamation boundaries of each forest unit, many of which contain private lands within the boundary. However, boundaries for some forest units were drawn to exclude some privately owned areas contained within the boundary. In order to ensure that private inholding areas were defined consistently in our analysis, we edited the boundaries so that they completely enclosed all private land parcels that were surrounded by USFS-owned lands. These included private parcels that shared only one corner with the proclamation boundary, so that National Forest boundaries encompassed all private land parcels arranged in a “checkerboard” pattern along forest edges. We additionally edited the boundaries to enclose access corridors along linear features, such as roads or rivers, so that inholdings connected to these corridors were contained within the forest boundary.

We identified private inholdings using the U.S. Geological Survey (USGS) Protected Areas Database (available at <https://www.usgs.gov/core-science-systems/science-analytics-and-synthesis/gap/science/protected-areas>; accessed January 2021). We selected all areas in the database with private ownership that were within our edited proclamation boundaries of National Forests. When doing so, we performed the ‘clip’ operation within ArcGIS 30 m inside the forest boundaries to avoid “sliver” polygons in the inholdings layer resulting from slight misalignments between the Protected Areas Database and the National Forest boundaries. Remaining slivers resulting from spatial errors >30 m were removed manually. Some private inholdings were adjacent to lakes and other water bodies; however, those water bodies are not areas where development could occur. To correct for this, we manually inspected all private inholdings features within National Forests to identify areas where a water body made up a substantial portion (>50%) of the inholding edge. We edited the inholdings polygons to exclude these

water bodies. We further edited the inholdings layer to remove linear features such as roads and rivers <50 m wide, because they are less likely to be developed and are not sufficiently large areas to provide a substantial opportunity for increasing protected areas. Furthermore, the Protected Areas Database did not consistently include these features as private inholdings in all National Forest units.

2.3. Assessing building extent and intensity in wildland vegetation

We used building point locations and the NLCD wildland vegetation map to generate two sets of raster maps quantifying impacts of buildings across the conterminous U.S. All raster outputs were generated at the native resolution of the NLCD (30 m). First, we determined extent of building impacts for our three ecological effect distances (100, 250, and 500 m) by classifying whether or not wildland vegetation pixels were within each distance to a building. Second, we determined intensity of

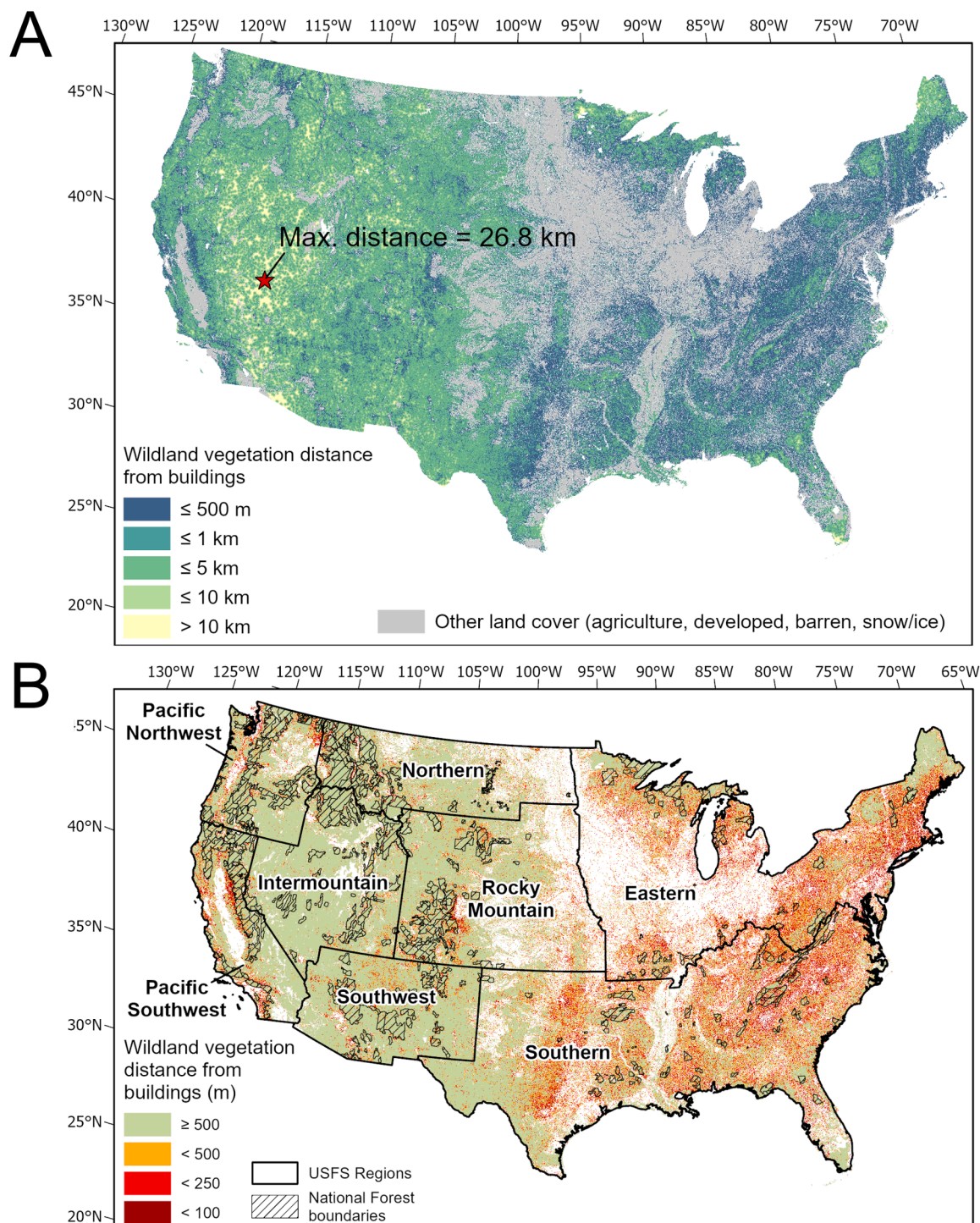


Fig. 2. Maps of wildland vegetation areas and distance to buildings in the conterminous U.S., indicating a) the location in the mainland U.S. with maximum distance from a building (red star), and b) three distance classes representing a range of ecological impacts, with National Forest units and U.S. Department of Agriculture Forest Service (USFS) Region boundaries.

building impacts by classifying wildland vegetation pixels according to the number of buildings within a 500 m radius. To summarize these intensities, we grouped building counts into four classes representing low, medium, high, and very high intensity, based on quartile ranges for all areas where building count was >0. We summarized the total areas within each distance of buildings, and within each quartile range of building counts within 500 m, for the entire conterminous U.S. and by USFS Region. For our assessments of building impacts within National Forest boundaries, within National Forest private inholdings, and within USFS-owned areas <500 m from a private inholding, we clipped the raster maps to each respective area. We then summarized vegetation proportions within each distance of a building and within each intensity class by National Forest unit and aggregated summaries by USFS Region. All raster maps, edited GIS layers, and summary tables are available through the USFS Research Data Archive (Carlson, Radeloff, Helmers, Mockrin, Hawbaker, & Pidgeon, 2023).

2.4. Accuracy assessment

The buildings dataset has both errors of omission (buildings that were missed) and commission (features such as boulders or ponds that were incorrectly classified as buildings). We assessed the effect of both types of errors on our maps and summary statistics based on 500 accuracy assessment samples, supplementing data from Carlson, Helmers, Hawbaker, Mockrin, and Radeloff (2022). Sample areas were circles with radii of 100, 250, and 500 m, randomly placed throughout the conterminous U.S. (Supplementary Material, Fig. S1). All sample areas were placed so that the focal pixel was a NLCD wildland vegetation

pixel, so that our sample set would best represent areas relevant for classifying wildland proximity to buildings (excluding areas with extensive agriculture or dense urban cover). Within each sample area, we overlaid building points with aerial imagery served by Esri in ArcGIS Pro in order to identify missing or mis-classified buildings. Using the methods described in Carlson et al. (2022), we counted the numbers of omission and commission errors within each sample area. We then determined whether the errors resulted in a change in the binary classification of whether the focal pixel was within a given distance class to the nearest building in order to determine rates of omission and commission errors for each distance. Lastly, we calculated the magnitude of building count errors for each distance.

3. Results

3.1. Buildings in all wildlands of the conterminous U.S.

We found that high proportions of wildland vegetation in the conterminous U.S. were in close proximity to buildings. The farthest distance from a building for any wildland vegetation pixel was 26.84 km, while ~90% of vegetation was within 5 km and ~50% was within 1 km (Fig. 2A). Focusing on our three ecological effect distances, nearly one-third (28.8%) of wildland vegetation was within 500 m of a building, 14.9% was within 250 m, and 5.0% was within 100 m (Fig. 2B). These proportions were much higher in the Eastern Region (57.8%, 32.4%, and 11.3% of wildland vegetation area within 500, 250, and 100 m of buildings, respectively) and the Southern Region (45.0%, 24.0%, and 8.0%, respectively) than in western Regions (Figs. 2 & 3), due to the

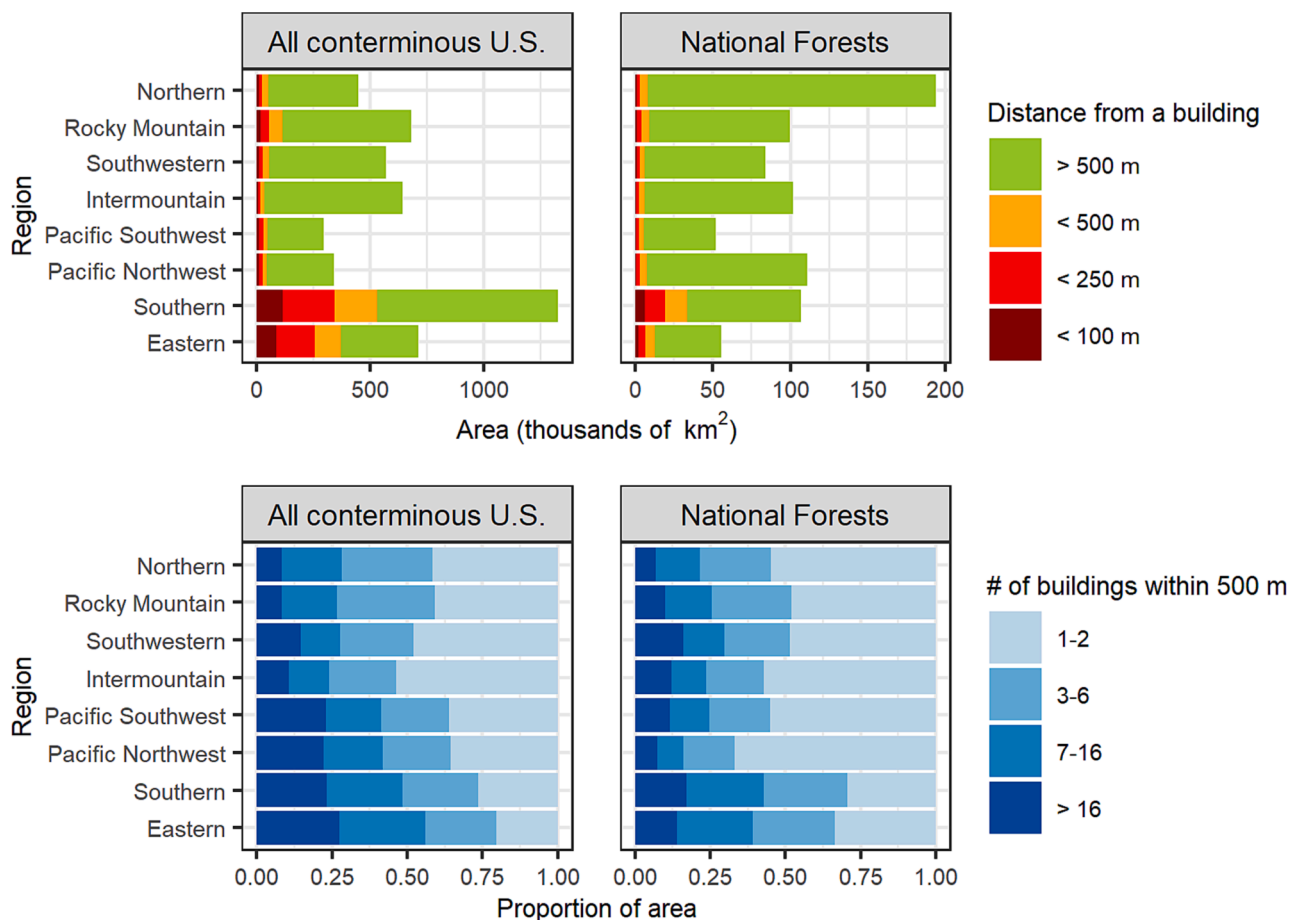


Fig. 3. Total wildland vegetation area for each U.S. Department of Agriculture Forest Service (USFS) administrative region that is within each disturbance zone distance (top row) and proportions of wildland vegetation area in the 500-m disturbance zone that is in each intensity class (bottom row). Left column shows proportions of area based on all wildland vegetation area in the conterminous U.S., and right column indicates proportions of area within National Forests only.

lower population density and greater abundance of public lands there. The Intermountain Region had the lowest proportions of wildland vegetation near buildings (5.8%, 2.3%, and 0.7% of area within each respective distance). As a result of these regional patterns, vegetation types that were more dominant in the eastern U.S. were more affected by buildings compared to vegetation types that dominate the western U.S. (Appendix A; [Supplementary Material, Fig. S2](#)). Forest vegetation had the greatest share of area in proximity to buildings (44.0% within 500 m), followed by wetlands (38.5%), grasslands (22.3%) and shrublands (21.3%).

Many wildland vegetation areas that were less than 500 m from a building also had high building intensities (i.e., were in proximity to more than one or two buildings). Median building counts were six, three, and two buildings within 500, 250, and 100 m respectively (see Appendix B for quartile ranges). The Eastern and Southern Regions, which had the highest proportions of area with buildings present within each distance of wildland vegetation, also had greater numbers of buildings within 500 m than western Regions ([Fig. 3](#); [Supplementary Material, Fig. S3](#)). The Pacific Northwest and the Pacific Southwest had relatively large wildland vegetation areas with no buildings, but those areas that were near buildings often had higher building intensities compared to

regions in the interior West ([Fig. 3](#)).

3.2. Buildings in National Forests and inholdings

National Forests, which we define here as the area within proclamation boundaries including all private inholdings, typically had much lower building extent and intensity than the conterminous U.S. as a whole. Across all USFS Regions, 12.5% of wildland vegetation in National Forests was within 500 m of a building, 5.5% was within 250 m, and 1.6% was within 100 m. Of all the wildland vegetation area in the conterminous U.S. that was not within 500 m of a building, a substantial proportion (18.9%) was within National Forest boundaries (which include 15.4% of all wildland vegetation area). However, the distribution of buildings in National Forest lands varied greatly by region. In the Eastern and Southern Regions, the proportions of wildland vegetation that were within 500 m of a building were 25.8% and 35.3%, respectively ([Fig. 3](#)). That proportion was as high as 70% for individual forest units (in Wayne National Forest; [Fig. 4](#); Appendix C). Building extent was much lower in western National Forests – for instance, in the Northern, Southwestern, Intermountain, and Pacific Northwest Regions, less than 10% of National Forest wildland vegetation was within 500 m

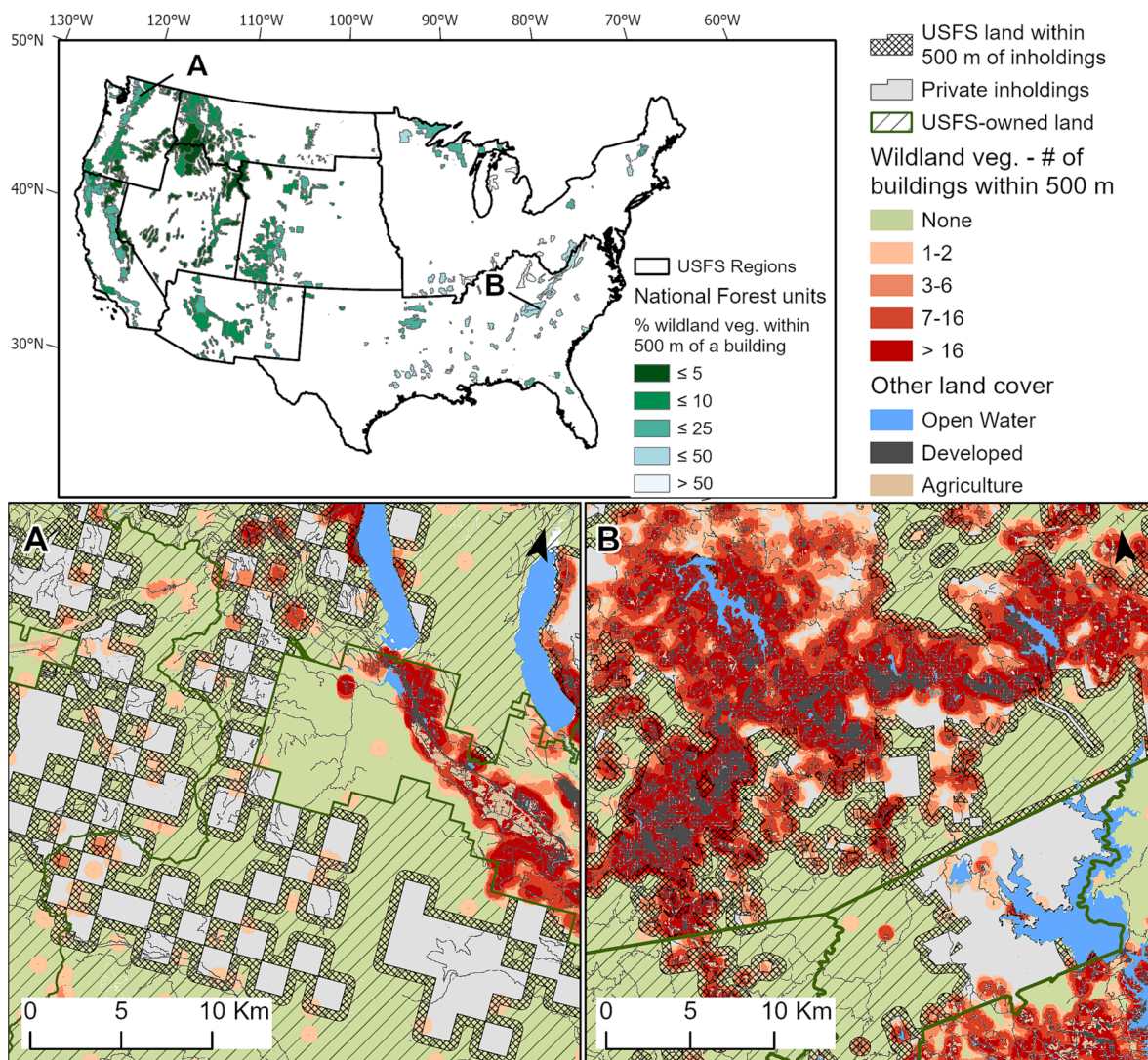


Fig. 4. Example maps illustrating developed and undeveloped private inholdings on National Forest lands and areas within a 500 m buffer. Example A (Mt. Baker-Snoqualmie and Okanogan-Wenatchee NFs, Washington) depicts an area with abundant undeveloped inholdings. Example B (Nantahala NF, North Carolina; Sumter NF, South Carolina, and Chattahoochee NF, Georgia) depicts an area where inholdings are highly developed, but where there are opportunities for conservation on lands with few or no buildings.

of a building (Fig. 3).

Of those wildland vegetation areas that were in proximity to buildings, National Forests typically had lower building intensities than the conterminous U.S. overall. No more than two buildings were present in 42% of National Forest wildland vegetation areas that were within 500 m of at least one building (representing the lowest quartile of building counts for the U.S. as a whole). There were important exceptions to that general pattern, however, and more than half of areas in the Eastern and Southern Regions were impacted by more than two buildings. In these Regions, building intensities approached the levels of the conterminous U.S. as a whole (Fig. 3). The starkest differences in building intensities between National Forests and overall wildland vegetation were in the Pacific Northwest and Pacific Southwest Regions (Fig. 3). In both of these Regions approximately two-thirds of overall wildland vegetation areas that were within 500 m of a building were affected by more than two buildings, but in National Forests these proportions were much lower: about one-third in the Pacific Northwest and one-half in the Pacific Southwest (Fig. 3).

Across the conterminous U.S., 15.4% of wildland vegetation area within National Forest boundaries was privately owned. These proportions were highest in the Eastern and Southern Regions, where 29.2% and 38.7%, respectively, of wildland vegetation area was privately owned, compared to 6–20% private ownership in the western Regions (Table 1; Appendix D). The abundance of private inholdings within National Forests means that many protected areas that are in proximity to inholdings may be impacted by current and future private development. We found that 13.5% of all USFS-owned (i.e., non-private) wildland vegetation areas were within 500 m of an inholding. That proportion ranged from 7.3% in the Pacific Northwest Region to 33.9% in the Eastern Region (Table 1).

While some inholdings were heavily developed, there were many that remained free of buildings (Figs. 4 & 5). Areas that were adjacent to private inholdings had fairly low building impacts overall, such that 75.6% of all wildland vegetation that was less than 500 m from an inholding edge was not yet within 500 m of a building. Private inholdings in the Eastern and Southern Regions were more highly developed, with around 60% of inholding areas within 500 m of a building, but there were still large areas that were not impacted by buildings both within inholdings and in USFS-owned areas adjacent to inholdings (Fig. 5; Appendices E–F). In all USFS Regions, roughly half of these areas were affected by only one or two buildings and few areas were affected by high building numbers (Fig. 5). However, because these areas are privately owned, there is potential for future development, which could rapidly increase the extent and intensity of buildings affecting wildland

vegetation on National Forest land.

3.3. Accuracy assessment

Although we found a considerable number of errors in the buildings data, these errors did not greatly affect our results. Of the 1,924 building footprints included in our accuracy assessment samples, 39 were falsely identified (2.0% commission error rate), and 608 buildings were missing from the classification (31.6% omission error rate). However, errors in the building footprints data were largely in areas where most buildings were classified accurately, so that our calculations of minimum building distances and building counts were not much affected. When we classified building presence/absence in wildland vegetation areas within 100, 250, and 500 m, commission error rates were 0.00%, 0.20%, and 0.40%, for each respective distance, and omission error rates were 1.20%, 1.80%, and 1.00%. Mean errors in building counts were also very low: -0.03 ± 0.28 , -0.19 ± 1.07 , and -1.14 ± 8.20 for the number of houses within 100, 250, and 500 m, respectively.

4. Discussion

We found that a substantial proportion of wildland vegetation in the conterminous U.S. is in close proximity to buildings and therefore likely faces negative ecological impacts from human presence. Nearly one-third of wildland vegetation in the U.S. overall was less than 500 m from a building, a distance where ecological effects are often substantial. The extent and intensity of buildings were even greater in the eastern half of the country, where about half of wildland vegetation was within 500 m of a building and greater areas were likely to be in proximity to several buildings. More wildland vegetation areas in western Regions were far from buildings, but many areas around concentrated population centers had high numbers of buildings in their proximity, particularly in the Pacific Southwest and Pacific Northwest Regions. Patterns in building extent and intensity are largely due to differences in histories of settlement and protected area establishments, with the eastern U.S. having fewer large protected areas, more extensive settlement, and therefore more fragmented protected areas than the West. However, development pressures near protected areas in the western U.S. will likely continue through the 21st century (Martinuzzi et al., 2015; Mockrin et al., 2022; Radeloff et al., 2010), leading to increased impacts on wildland areas that are presently free from buildings.

While our assessment approach can be used to identify conservation opportunities in various land types (including on lands adjacent to National Forest boundaries), we focused on assessing conservation opportunities in National Forests and their inholdings because the USFS is the largest public landowner in the U.S. with holdings in both the East and West, and therefore conservation actions targeting National Forests can have substantial impact. Indeed, we found National Forests play a vital role in maintaining wildland areas that are free from buildings. About 15% of wildland vegetation area in the conterminous U.S. (nearly 1 million km²) is in National Forests, and of the 3.8 million km² that were not within 500 m of a building, nearly one-fifth was in National Forests. However, we found that approximately 10% of this un-impacted area in National Forests was also within 500 m of a private inholding. These inholdings are both uniquely vulnerable to future development, but also opportune locations for conservation, offering valuable opportunities to ensure access to public lands for recreation and enhance natural resource management, while also improving the effectiveness of wildfire risk management and response.

Ideally our maps of building proximity (Fig. 4) can be used in conjunction with other biological, economic, and social criteria commonly considered in conservation planning, such as biodiversity or habitat rarity indices, presence of threatened or endangered species, connectivity metrics, or recreational and cultural values. Other important considerations may include reducing wildfire risk or improving safety (suppression access, egress/ingress for residents). Determining

Table 1

Summaries of wildland vegetation area in National Forests in the conterminous U.S., summarized by USDA Forest Service Region. For wildland vegetation area in National Forests, values in parentheses are areas as a percent of all wildland vegetation in the Region.

Region	Wildland veg. area in National Forests [km ²] (% of total wildland veg. area for the Region)	% National Forest wildland veg. area in private inholdings	% USFS-owned wildland veg. area < 500 m from a private inholding
Northern	194,684 (42.9)	6.2	7.4
Rocky Mountain	100,727 (15.6)	19.7	18.1
Southwestern	85,009 (24.3)	9.2	10.3
Intermountain	102,635 (14.7)	9.6	8.5
Pacific	52,637 (9.1)	13.3	14.6
Southwest			
Pacific	111,833 (35.8)	8.3	7.3
Northwest			
Southern	112,900 (7.8)	38.7	31.0
Eastern	57,385 (7.0)	29.2	33.9
Conterminous U.S. (totals)	817,812 (15.4)	15.4	13.5

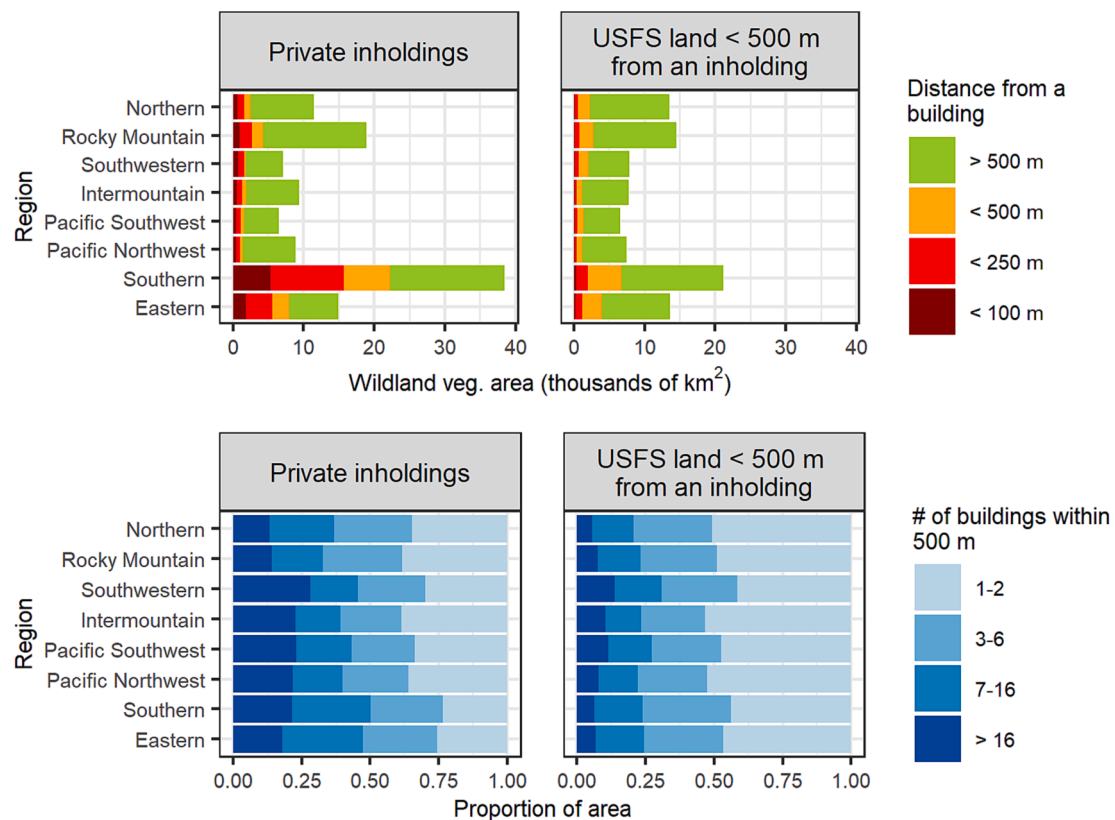


Fig. 5. Amount of wildland vegetation area in each disturbance zone distance (top row), and the proportions of wildland vegetation area in the 500-m disturbance zone that is in each intensity class (bottom row), by U.S. Department of Agriculture Forest Service (USFS) administrative region. Results are summarized for private inholdings areas (left column) and for USFS-owned lands within 500 m of an inholding (right column).

exactly how and where to focus these investments depends on the conservation and management objective, which was beyond the scope of our study. Furthermore, our assessments do not identify which areas that are free of buildings may be impacted by other disturbances, e.g., from recreational use, livestock grazing, or roads. Lastly, we did not attempt to predict where future development is most likely to occur, because this depends on a multitude of factors including topographic and climatic suitability, water availability, connectivity to existing communities, zoning laws, landowner preferences, and the attractiveness of natural amenities (Chi & Marcouiller, 2013). However, the presence of buildings in and near protected areas is a particularly important conservation threat in the U.S. and in other countries with high levels of amenity-driven housing development (Abrams, Gosnell, Gill, & Klepeis, 2012; Mockrin et al., 2018). Assessing proximity to buildings is therefore an important criterion for identifying conservation targets, particularly on lands where development is likely to expand or intensify in the future.

Our findings focus on the U.S., but can inform conservation efforts in other global protected area networks that are similarly affected by building fragmentation (e.g., the European Union's Natura 2000 network; Ledda, Serra, & De Montis, 2019) and that also face heavy development pressures (de la Fuente et al., 2020). Maps of the global human footprint reveal that temperate and tropical biomes, where most of the world's population lives, are already highly impacted by human development, and are therefore conservation priorities (Riggio et al., 2020). Protected areas worldwide vary greatly in their spatial continuity and protections, and housing contributes to fragmentation of critical conservation areas in many regions that are experiencing rapid population growth and resource development (Rodríguez-Rodríguez, Sebastiao, Salvo Tierra, & Martínez-Vega, 2019; Schulze et al., 2018). Targeting efforts to limit development within protected areas for conservation actions can therefore provide considerable benefits for global

biodiversity conservation.

Assessing building proximity in all wildland vegetation of the conterminous U.S. was possible using a newly available, spatially complete building footprint dataset. These data were derived from growing archives of high-resolution satellite imagery and made use of new efficient classification algorithms. The advantage of a building footprint dataset in this study, as opposed to housing data alone, is that building footprints also include farm structures, warehouses, commercial and industrial buildings, and structures associated with natural resource extraction (e.g., oil and gas wells; Carlson et al., 2022). Building presence is not a perfect indicator of various land use types that may have ecological impact, but including these non-housing structures provides a more complete assessment of overall building impacts that have not been considered in prior assessments of housing growth around U.S. protected areas based on census data. We found that the building data missed a fair number of buildings, but those errors had minimal effects on our analyses because they were typically near other buildings that were mapped correctly. The feasibility of mapping building footprints continuously across large spatial extents is therefore highly valuable for identifying conservation priorities. Building footprint data is becoming more widely available around the world, allowing similar approaches to be implemented globally. For example, Microsoft data is currently available for Canada, South America, Africa, and Australia (<https://www.microsoft.com/en-us/maps/building-footprints>; accessed November 2022), and OpenStreetMap building footprints are available for Europe through ArcGIS Hub (https://hub.arcgis.com/datasets/652793c501a145b992a4cfd35b4c910e_0; accessed December 2022).

5. Implications for conservation of U.S. National Forest lands

Housing growth within National Forest lands threatens to degrade

habitat quality, limit connectivity between habitat areas (Hansen & DeFries, 2007; Santini, Saura, & Rondinini, 2016) and increase disturbances from human activities, including recreational use (Schulze et al., 2018). Furthermore, continued development threatens access to public lands and amenity values (Stein et al., 2007). Prioritizing conservation in National Forest inholdings would help to maintain the ecological integrity of these important protected areas, preventing further impacts of development on biodiversity and ecological values. Despite the widespread impact of buildings on vegetation in the U.S. overall and in National Forests, our assessment demonstrates that there are numerous opportunities to conserve lands that are not yet affected. Our broad assessments reveal that these opportunities exist in both the eastern and western U.S., while our detailed maps of building proximity to wildlands can be used to identify where there are presently inholdings with low or no development within National Forest units (Fig. 5). Conservation actions in these areas could include federal acquisitions, which would increase areas under formal protected status where further development is prohibited, or of community-led efforts supporting other goals of the America the Beautiful plan, such as supporting local control of resources and improving access for recreation (U.S. Department of the Interior, 2021). Given the development pressures faced by National Forest lands, such actions have great potential to maintain undisturbed wildlands, reducing further fragmentation and impacts to biodiversity.

Declaration of Competing Interest

The authors declare that they have no known competing financial

Appendix

Appendix A. . Percentages of wildland vegetation area within three ecological effect distances of a building, by vegetation type, for each USDA Forest Service Region and for the entire conterminous U.S.

Vegetation type	Region	Total area in veg. class (km ²)	% area within 500 m of a building	% area within 250 m of a building	% area within 100 m of a building
Forest	R1: Northern	115,667.4	9.7	4.5	1.4
	R2: Rocky Mountain	121,096.6	5.1	1.9	0.5
	R3: Southwestern	157,631.8	16.4	8.4	3.1
	R4: Intermountain	111,648.6	19.9	9.2	2.9
	R5: Pacific	88,736.4	9.4	3.8	1.2
	Southwest				
	R6: Pacific	88,304.8	21.8	11.0	4.0
	Northwest				
	R8: Southern	674,157.7	59.4	33.6	11.4
	R9: Eastern	614,592.2	61.0	34.8	12.4
Grassland	Conterminous U.S.	1,971,835.5	44.0	24.6	8.5
	R1: Northern	207,313.9	14.3	5.6	1.7
	R2: Rocky Mountain	84,409.0	4.9	1.9	0.6
	R3: Southwestern	65,240.1	12.4	5.3	1.7
	R4: Intermountain	389,804.4	20.1	8.2	2.5
	R5: Pacific	85,960.9	8.9	3.6	1.0
	Southwest				
	R6: Pacific	56,821.6	27.8	15.3	6.2
	Northwest				
	R8: Southern	207,961.1	44.1	23.2	8.3
Shrubland	R9: Eastern	20,284.4	67.9	45.3	21.6
	Conterminous U.S.	1,117,795.5	22.3	10.6	3.7
	R1: Northern	227,519.4	10.4	4.5	1.4
	R2: Rocky Mountain	541,789.3	5.6	2.2	0.6
	R3: Southwestern	274,062.0	14.9	7.4	2.7
	R4: Intermountain	255,924.7	13.2	5.8	1.8
	R5: Pacific	488,258.0	10.9	4.7	1.6
	Southwest				
	R6: Pacific	249,276.2	17.1	8.6	3.2
	Northwest				
Wetland	R8: Southern	724,382.4	40.8	21.7	7.3
	R9: Eastern	213,924.9	53.6	32.3	13.0
	Conterminous U.S.	2,975,136.8	21.3	11.0	3.9
	R1: Northern	15,139.9	33.7	14.2	3.8

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Vegetation type	Region	Total area in veg. class (km ²)	% area within 500 m of a building	% area within 250 m of a building	% area within 100 m of a building
	R2: Rocky Mountain	8,844.6	25.0	10.8	2.9
	R3: Southwestern	8,271.9	45.5	26.4	8.3
	R4: Intermountain	19,569.5	37.0	15.6	4.2
	R5: Pacific Southwest	2,621.2	25.8	12.9	3.9
	R6: Pacific Northwest	4,316.1	32.8	15.3	4.2
	R8: Southern	237,689.2	33.8	15.5	4.1
	R9: Eastern	166,989.8	46.6	23.3	6.3
	Conterminous U.S.	463,442.2	38.5	18.3	5.0

Appendix B. . Numbers of buildings used to define intensity classes used to summarize the number of buildings in disturbance zones, based on quartile ranges. Ranges are defined separately for three ecological effect distances.

Effect distance	Low-intensity	Medium-intensity	High-intensity	Very high-intensity
100 m	1	2	3–4	≥5
250 m	1	2–3	4–7	≥8
500 m	1–2	3–6	7–16	≥17

Appendix C. . Wildland vegetation area within three ecological effect distances of a building, for individual National Forest units in the conterminous U.S. Areas include all public and private lands within National Forest proclamation boundaries. NF = National forest; NSA = National scenic area; NRA = National recreation area; MA = Management area; NTP = National tallgrass Prairie.

Region	National Forest Unit	Total wild. veg. area in NF proclamation boundaries (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R1: Northern	Beaverhead-Deerlodge NF	14,474.0	4.56	1.53	0.36
	Bighorn NF	4,463.5	4.74	1.37	0.27
	Bitterroot NF	6,723.1	2.98	1.08	0.27
	Bridger-Teton NF	13,751.9	4.14	1.39	0.35
	Caribou-Targhee NF	12,367.1	3.84	1.37	0.38
	Colville NF	4,693.8	4.45	1.32	0.27
	Custer Gallatin NF	13,446.5	5.84	2.22	0.60
	Dakota Prairie Grasslands	6,118.2	6.33	1.74	0.34
	Flathead NF	10,312.3	5.61	2.49	0.75
	Helena-Lewis and Clark NF	12,504.4	5.11	1.74	0.41
	Idaho Panhandle NF	11,609.6	7.37	3.12	0.91
	Kootenai NF	10,581.2	8.49	3.90	1.23
	Lolo NF	10,549.2	5.26	2.01	0.57
	Nez Perce-Clearwater NF	16,517.8	2.77	0.97	0.23
	Payette NF	9,745.0	3.35	1.10	0.25
	Salmon-Challis NF	17,691.8	2.14	0.68	0.15
	Shoshone NF	9,336.4	3.33	1.08	0.25
	Wallowa-Whitman NF	9,798.1	4.21	1.27	0.28
	Arapaho and Roosevelt NF	9,704.0	15.5	7.10	2.30
	Black Hills NF	6,241.9	23.27	10.39	3.27
R2: Rocky Mountain	Carson NF	6,374.5	8.44	3.37	1.02
	Grand Mesa, Uncompahgre and Gunnison NF	12,369.3	6.55	2.46	0.64
	Medicine Bow-Routt NF	18,358.9	6.30	2.08	0.47
	Nebraska NF	7,744.3	7.94	2.68	0.64
	Pike and San Isabel NF	14,724.3	15.15	6.07	1.71
	Rio Grande NF	7,602.0	5.69	2.25	0.67
	San Juan NF	8,024.0	9.91	4.33	1.35
	White River NF	9,583.6	8.43	3.50	1.09
	Apache-Sitgreaves NF	8,401.4	9.34	4.34	1.82
	Cibola NF	12,352.9	9.30	3.43	0.87
	Coconino NF	7,866.1	10.55	5.12	2.18
	Coronado NF	7,201.6	5.41	1.98	0.53
	Gila NF	13,674.3	5.02	1.80	0.47
	Kaibab NF	6,284.6	5.63	2.13	0.61
R3: Southwestern	Lincoln NF	5,057.1	12.63	5.84	2.11
	Prescott NF	5,657.6	7.81	3.42	1.23
	Santa Fe NF	6,737.2	11.16	4.49	1.34
	Tonto NF	11,776.6	8.11	3.56	1.34
	Ashley NF	5,073.2	2.99	0.95	0.21
	Boise NF	10,197.4	6.08	2.36	0.73
	Dixie NF	6,822.2	5.00	1.90	0.56
R4: Intermountain					

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Region	National Forest Unit	Total wild. veg. area in NF proclamation boundaries (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R5: Pacific Southwest	Eldorado NF	3,106.1	18.05	6.60	1.63
	Fishlake NF	7,209.4	4.27	1.48	0.33
	Humboldt-Toiyabe NF	26,993.6	3.98	1.62	0.54
	Inyo NF	7,787.1	4.90	1.64	0.42
	Lake Tahoe Basin MA	744.9	29.42	16.12	6.93
	Manti-La Sal NF	5,632.7	5.29	1.70	0.38
	Sawtooth NF	8,720.0	3.92	1.38	0.36
	Stanislaus NF	4,307.2	17.94	7.48	2.36
	Tahoe NF	4,705.7	18.15	7.49	2.34
	Uinta-Wasatch-Cache NF	11,336.1	8.07	3.15	0.87
	Angeles NF	2,761.0	12.94	4.91	1.33
	Cleveland NF	2,222.8	22.03	10.03	3.39
	Lassen NF	6,322.1	4.85	1.79	0.52
	Los Padres NF	7,786.4	8.05	3.28	0.94
	Mendocino NF	4,092.1	9.85	3.42	0.78
	Plumas NF	5,871.7	12.92	5.11	1.45
	San Bernardino NF	3,008.2	17.85	8.41	3.30
	Sequoia NF	4,624.4	11.54	4.04	0.97
	Shasta-Trinity NF	10,498.1	10.41	4.03	1.06
	Sierra NF	5,450.8	20.71	8.49	2.46
R6: Pacific Northwest	Columbia River Gorge NSA	870.8	37.27	20.00	7.02
	Deschutes NF	7,526.6	9.17	4.57	1.92
	Fremont-Winema NF	10,376.9	2.95	0.94	0.21
	Gifford Pinchot NF	5,172.7	16.10	5.36	1.07
	Klamath NF	6,667.3	9.00	2.85	0.60
	Malheur NF	7,592.3	3.12	0.87	0.16
	Modoc NF	8,147.1	3.77	1.18	0.24
	Mt. Baker-Snoqualmie NF	7,588.8	11.61	3.81	0.82
	Mt. Hood NF	4,036.3	7.55	2.34	0.47
	Ochoco NF	3,723.4	7.18	3.01	1.14
	Okanogan-Wenatchee NF	15,979.4	6.76	2.41	0.62
	Olympic NF	2,663.5	10.6	3.65	0.87
	Rogue River-Siskiyou NF	7,297.6	5.86	1.80	0.38
	Siuslaw NF	2,547.8	16.02	4.96	0.91
	Six Rivers NF	4,855.8	11.26	4.19	1.06
	Umatilla NF	5,845.4	3.32	0.89	0.16
	Umpqua NF	4,094.0	7.99	2.40	0.47
	Willamette NF	6,848.0	6.83	2.26	0.53
	Chattahoochee-Oconee NF	6,311.8	45.94	27.1	9.93
	Cherokee NF	4,350.0	40.42	23.71	8.08
R8: Southern	Daniel Boone NF	7,335.8	50.87	25.14	7.13
	Francis Marion and Sumter NF	4,986.7	35.96	16.91	5.01
	George Washington and Jefferson NF	12,668.8	33.11	15.81	4.58
	Hoosier NF	2,055.0	62.04	29.81	7.57
	Kisatchie NF	4,021.2	29.48	13.83	4.25
	Land Between the Lakes NRA	646.7	3.47	1.03	0.19
	Mark Twain NF	10,345.9	39.08	16.65	4.27
	Monongahela NF	6,357.5	25.3	10.89	2.79
	NFs in Alabama	4,759.6	28.28	12.29	3.24
	NFs in Florida	5,385.1	11.94	6.11	2.25
	NFs in Mississippi	8,418.2	34.51	15.13	3.98
	NFs in North Carolina	10,900.0	49.80	30.83	11.88
	NFs in Texas	6,164.0	39.58	18.89	5.77
	Ouachita NF	9,918.9	19.03	8.03	2.05
	Ozark-St. Francis NF	5,687.0	23.46	8.85	1.90
	Shawnee NF	2,588.0	50.58	22.67	5.57
	Allegheny NF	2,798.3	24.94	10.92	3.35
	Chequamegon-Nicolet NF	7,517.0	20.79	9.09	2.75
	Chippewa NF	5,050.5	26.34	11.74	3.56
	Green Mountain and Finger Lakes NF	3,162.8	39.82	21.73	7.39
R9: Eastern	Hiawatha NF	4,820.7	22.63	9.65	2.64
	Huron-Manistee NF	7,148.6	51.19	26.52	8.39
	Midewin NTP	39.6	35.27	11.89	2.52
	Ottawa NF	6,155.9	18.19	6.95	1.68
	Superior NF	13,978.6	10.67	4.36	1.21
	Wayne NF	2,942.9	70.24	34.83	8.54
	White Mountain NF	3,770.4	13.87	6.39	2.06

Appendix D. . Percentages of wildland vegetation area in National Forest units that are privately owned and percentages of USFS-owned area that are within 500 m of an inholding. NF = National forest; NSA = National scenic area; NRA = National recreation area; MA = Management area; NTP = National tallgrass Prairie

Region	National Forest Unit	% total area that is private inholdings	% USFS-owned area that is within 500 m of an inholding
R1: Northern	Beaverhead-Deerlodge NF	5.58	9.00
	Bighorn NF	0.37	1.25
	Bitterroot NF	3.13	3.60
	Bridger-Teton NF	0.70	1.66
	Caribou-Targhee NF	4.68	6.65
	Colville NF	4.67	7.28
	Custer Gallatin NF	10.42	10.60
	Dakota Prairie Grasslands	14.51	18.54
	Flathead NF	7.35	4.54
	Helena-Lewis and Clark NF	10.17	11.17
	Idaho Panhandle NF	12.01	13.38
	Kootenai NF	14.58	11.22
	Lolo NF	13.64	10.47
	Nez Perce-Clearwater NF	4.26	3.78
	Payette NF	2.47	4.76
	Salmon-Challis NF	0.74	2.97
	Shoshone NF	1.00	2.37
	Wallowa-Whitman NF	2.75	5.13
R2: Rocky Mountain	Arapaho and Roosevelt NF	30.74	15.26
	Black Hills NF	17.46	29.6
	Carson NF	6.35	11.92
	Grand Mesa, Uncompahgre and Gunnison NF	6.64	6.88
	Medicine Bow-Routt NF	30.86	15.88
	Nebraska NF	45.75	19.15
	Pike and San Isabel NF	23.77	19.14
	Rio Grande NF	5.51	8.94
	San Juan NF	9.84	12.52
	White River NF	6.69	8.22
R3: Southwestern	Apache-Sitgreaves NF	3.73	6.43
	Cibola NF	35.62	13.55
	Coconino NF	4.09	8.01
	Coronado NF	3.03	7.83
	Gila NF	3.42	7.79
	Kaibab NF	2.10	4.80
	Lincoln NF	11.11	18.78
	Prescott NF	10.32	12.74
	Santa Fe NF	7.13	12.49
	Tonto NF	2.72	5.63
	Ashley NF	2.05	3.41
	Boise NF	10.94	7.91
	Dixie NF	4.44	7.14
R4: Intermountain	Eldorado NF	21.02	12.81
	Fishlake NF	5.41	6.52
	Humboldt-Toiyabe NF	5.65	7.31
	Inyo NF	3.64	5.13
	Lake Tahoe Basin MA	13.03	3.82
	Manti-La Sal NF	4.69	5.60
	Sawtooth NF	3.57	6.02
	Stanislaus NF	16.31	12.02
	Tahoe NF	28.62	12.48
	Uinta-Wasatch-Cache NF	24.41	10.49
	Angeles NF	4.14	10.39
	Cleveland NF	15.96	22.84
	Lassen NF	18.32	15.54
	Los Padres NF	8.48	12.52
	Mendocino NF	13.57	17.36
R5: Pacific Southwest	Plumas NF	16.93	16.10
	San Bernardino NF	10.66	17.76
	Sequoia NF	3.24	6.83
	Shasta-Trinity NF	22.15	9.11
	Sierra NF	6.33	7.91
	Columbia River Gorge NSA	47.74	12.35
	Deschutes NF	15.06	4.25
	Fremont-Winema NF	11.72	9.53
	Gifford Pinchot NF	0.96	1.57
	Klamath NF	12.23	9.01
R6: Pacific Northwest	Malheur NF	8.19	6.56
	Modoc NF	14.18	9.38
	Mt. Baker-Snoqualmie NF	7.92	5.42
	Mt. Hood NF	0.56	1.43
	Ochoco NF	19.20	10.21
	Okanogan-Wenatchee NF	4.89	6.09

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Region	National Forest Unit	% total area that is private inholdings	% USFS-owned area that is within 500 m of an inholding
R8: Southern	Olympic NF	6.39	8.76
	Rogue River-Siskiyou NF	6.24	7.67
	Siuslaw NF	5.86	15.60
	Six Rivers NF	7.55	6.85
	Umatilla NF	3.32	4.36
	Umpqua NF	3.43	5.57
	Willamette NF	3.43	4.74
	Chattahoochee-Oconee NF	43.84	10.97
	Cherokee NF	38.20	1.96
	Daniel Boone NF	59.59	19.18
	Francis Marion and Sumter NF	50.08	23.21
	George Washington and Jefferson NF	39.85	14.50
	Hoosier NF	56.44	30.95
	Kisatchie NF	38.17	27.10
	Land Between the Lakes NRA	0.04	0.74
	Mark Twain NF	41.90	35.56
	Monongahela NF	40.24	12.95
	NFs in Alabama	40.07	24.10
	NFs in Florida	10.17	11.64
	NFs in Mississippi	43.25	30.56
	NFs in North Carolina	50.89	6.92
	NFs in Texas	16.80	5.33
	Ouachita NF	28.67	22.24
	Ozark-St. Francis NF	15.59	27.15
R9: Eastern	Shawnee NF	53.31	33.95
	Allegheny NF	25.73	24.25
	Chequamegon-Nicolet NF	20.49	27.36
	Chippewa NF	21.27	32.23
	Green Mountain and Finger Lakes NF	46.84	20.60
	Hiawatha NF	24.72	23.91
	Huron-Manistee NF	45.64	31.69
	Midewin NTP	12.01	35.14
	Ottawa NF	36.41	6.26
	Superior NF	20.02	25.98
	Wayne NF	65.99	28.66
	White Mountain NF	13.06	12.90

Appendix E. . Wildland vegetation area within three ecological effect distances of a building, for private inholdings on individual National Forest units in the conterminous U.S. NF = National forest; NSA = National scenic area; NRA = National recreation area; MA = Management area; NTP = National tallgrass Prairie

Region	National Forest Unit	Total wild. veg. area in private inholdings (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R1: Northern	Beaverhead-Deerlodge NF	808.0	28.35	13.61	4.31
	Bighorn NF	16.7	39.64	22.78	8.36
	Bitterroot NF	210.6	29.73	17.12	6.04
	Bridger-Teton NF	96.6	69.14	43.46	18.67
	Caribou-Targhee NF	579.2	23.96	11.31	4.04
	Colville NF	219.0	17.34	9.76	2.96
	Custer Gallatin NF	1,400.9	26.70	13.27	4.34
	Dakota Prairie Grasslands	887.8	17.30	5.96	1.41
	Flathead NF	758.4	41.42	24.56	8.70
	Helena-Lewis and Clark NF	1,271.8	18.34	8.67	2.72
	Idaho Panhandle NF	1,394.7	27.84	16.43	5.86
	Kootenai NF	1,543.0	30.87	19.26	7.35
	Lolo NF	1,438.8	16.84	9.17	3.34
	Nez Perce-Clearwater NF	704.3	16.12	8.45	2.72
	Payette NF	241.1	27.39	13.81	4.33
	Salmon-Challis NF	130.6	44.95	24.52	8.09
	Shoshone NF	92.9	55.34	30.03	9.94
	Wallowa-Whitman NF	268.4	26.97	13.03	4.32
R2: Rocky Mountain	Arapaho and Roosevelt NF	2,982.7	30.9	17.15	6.50
	Black Hills NF	1,089.8	56.19	35.37	14.84
	Carson NF	404.6	46.72	28.81	12.08
	Grand Mesa, Uncompahgre and Gunnison NF	821.4	44.25	23.00	7.37
	Medicine Bow-Routt NF	5,665.4	12.65	4.73	1.19
	Nebraska NF	3,542.8	14.53	5.13	1.26
	Pike and San Isabel NF	3,499.9	28.68	14.59	5.22
	Rio Grande NF	418.6	45.40	25.67	9.75
	San Juan NF	789.6	51.72	30.66	11.69
	White River NF	640.8	48.92	29.24	11.90

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Region	National Forest Unit	Total wild. veg. area in private inholdings (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R3: Southwestern	Apache-Sitgreaves NF	313.5	81.23	65.09	39.38
	Cibola NF	4,382.5	17.41	7.16	1.97
	Coconino NF	322.0	80.71	65.48	41.37
	Coronado NF	217.9	44.87	27.44	11.31
	Gila NF	467.9	41.71	24.79	9.26
	Kaibab NF	132.0	64.71	42.79	19.52
	Lincoln NF	562.0	54.87	36.97	16.55
	Prescott NF	583.6	28.42	18.75	9.33
	Santa Fe NF	480.4	51.07	30.96	12.65
	Tonto NF	319.8	73.83	58.36	34.89
R4: Intermountain	Ashley NF	104.2	19.57	9.64	3.06
	Boise NF	1,115.6	21.36	11.45	4.74
	Dixie NF	303.0	40.49	22.50	9.06
	Eldorado NF	648.2	20.41	10.25	3.64
	Fishlake NF	390.0	22.35	10.50	2.86
	Humboldt-Toiyabe NF	1,521.6	29.75	17.07	7.20
	Inyo NF	278.3	22.99	11.44	4.60
	Lake Tahoe Basin MA	89.7	75.28	57.42	34.65
	Manti-La Sal NF	264.3	23.69	11.92	4.06
	Sawtooth NF	311.5	25.02	12.97	4.61
	Stanislaus NF	695.3	33.49	18.86	8.28
	Tahoe NF	1,324.7	31.16	16.37	6.34
	Uinta-Wasatch-Cache NF	2,767.4	16.85	8.01	2.60
	Angeles NF	108.4	70.63	44.41	17.84
R5: Pacific Southwest	Cleveland NF	340.6	60.44	38.31	16.24
	Lassen NF	1,149.0	9.46	4.37	1.52
	Los Padres NF	644.1	39.69	21.39	7.42
	Mendocino NF	536.2	21.46	9.23	2.39
	Plumas NF	979.8	32.16	17.35	6.35
	San Bernardino NF	297.2	62.14	43.26	23.64
	Sequoia NF	148.0	52.95	32.51	12.64
	Shasta-Trinity NF	2,289.1	17.54	9.18	3.08
	Sierra NF	340.7	66.45	43.51	19.64
	Columbia River Gorge NSA	407.5	55.29	33.55	13.09
R6: Pacific Northwest	Deschutes NF	1,110.0	22.05	15.37	8.70
	Fremont-Winema NF	1,209.9	7.90	3.55	1.06
	Gifford Pinchot NF	49.4	27.12	18.74	8.17
	Klamath NF	790.1	14.65	7.07	2.16
	Malheur NF	617.5	15.71	5.58	1.22
	Modoc NF	1,149.3	8.69	3.36	0.77
	Mt. Baker-Snoqualmie NF	601.4	16.02	7.05	2.38
	Mt. Hood NF	22.2	22.44	11.93	5.04
	Ochoco NF	707.8	19.73	10.39	4.86
	Okanogan-Wenatchee NF	782.1	31.94	19.47	7.68
	Olympic NF	170.3	22.19	13.31	5.31
	Rogue River-Siskiyou NF	446.6	15.36	7.67	2.53
	Siuslaw NF	143.7	40.50	19.97	5.39
	Six Rivers NF	353.9	45.25	26.39	8.99
	Umatilla NF	192.7	12.82	5.39	1.54
	Umpqua NF	139.7	23.00	11.43	3.49
R8: Southern	Willamette NF	231.7	20.36	13.08	5.78
	Chattahoochee-Oconee NF	2,766.9	79.34	53.78	21.36
	Cherokee NF	1,661.5	81.54	54.98	20.04
	Daniel Boone NF	4,371.1	66.08	35.32	10.53
	Francis Marion and Sumter NF	2,408.3	54.11	28.31	9.08
	George Washington and Jefferson NF	5,048.8	60.68	33.31	10.46
	Hoosier NF	1,159.8	81.95	44.70	12.34
	Kisatchie NF	1,534.8	50.13	27.82	9.78
	Land Between the Lakes NRA	0.2	39.85	28.04	6.64
	Mark Twain NF	4,075.4	65.46	32.72	9.03
	Monongahela NF	2,558.0	47.27	22.91	6.31
	NFs in Alabama	1,907.1	47.09	22.82	6.37
	NFs in Florida	547.7	49.81	36.57	17.81
	NFs in Mississippi	3,640.5	55.38	28.34	8.23
	NFs in North Carolina	5,547.0	78.87	54.30	22.19
	NFs in Texas	988.4	59.99	36.40	13.95
R9: Eastern	Ouachita NF	2,843.4	41.55	21.38	6.19
	Ozark-St. Francis NF	886.4	62.93	32.59	8.30
	Shawnee NF	1,269.6	70.93	36.45	9.73
	Allegheny NF	720.2	51.65	29.00	10.96
	Chequamegon-Nicolet NF	1,540.3	57.49	33.60	11.95
	Chippewa NF	1,074.0	68.26	39.34	13.56
	Green Mountain and Finger Lakes NF	1,425.4	67.16	40.99	14.93

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Region	National Forest Unit	Total wild. veg. area in private inholdings (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
	Hiawatha NF	1,191.7	57.99	30.88	9.50
	Huron-Manistee NF	3,262.5	79.52	48.40	17.04
	Midewin NTP	4.2	37.53	17.92	4.90
	Ottawa NF	2,241.1	33.56	15.63	4.19
	Superior NF	2,798.9	32.74	16.59	5.11
	Wayne NF	1,846.2	82.48	45.28	11.89
	White Mountain NF	482.4	60.19	35.31	13.40

Appendix F. . Wildland vegetation area within three ecological effect distances of a building, for USFS-owned lands within 500 m of private inholdings on individual National Forest units in the conterminous U.S. NF = National forest; NSA = National scenic area; NRA = National recreation area; MA = Management area; NTP = National tallgrass Prairie

Region	National Forest Unit	Total USFS-owned wild. veg. area within 500 m of inholdings (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R1: Northern	Beaverhead-Deerlodge NF	1302.7	16.22	25.70	15.25
	Bighorn NF	241.8	27.21	26.42	14.44
	Bitterroot NF	1425.6	14.97	26.58	15.87
	Bridger-Teton NF	1134.5	6.41	21.50	13.66
	Caribou-Targhee NF	467.9	28.63	26.44	12.88
	Colville NF	1396.9	18.15	26.39	13.91
	Custer Gallatin NF	1553.5	14.36	28.43	17.47
	Dakota Prairie Grasslands	1186.8	24.43	27.18	13.25
	Flathead NF	1105.0	15.90	24.84	14.19
	Helena-Lewis and Clark NF	624.7	14.52	29.65	18.49
	Idaho Panhandle NF	1480.4	20.80	28.72	16.53
	Kootenai NF	55.9	23.29	26.35	14.89
	Lolo NF	1847.6	37.45	32.10	15.67
	Nez Perce-Clearwater NF	851.6	18.47	22.87	13.53
	Payette NF	2916.2	8.60	25.11	15.91
	Salmon-Challis NF	1482.9	4.81	23.43	17.16
	Shoshone NF	2818.9	20.54	28.56	15.44
	Wallowa-Whitman NF	679.5	23.82	26.77	14.30
	Arapaho and Roosevelt NF	1004.9	26.25	27.20	14.58
R2: Rocky Mountain	Black Hills NF	221.1	29.22	28.62	17.80
	Carson NF	787.5	27.25	29.84	18.55
	Grand Mesa, Uncompahgre and Gunnison NF	540.2	47.47	33.93	19.07
	Medicine Bow-Routt NF	759.9	27.00	29.01	16.10
	Nebraska NF	1673.4	12.08	25.33	15.42
	Pike and San Isabel NF	630.2	51.62	36.76	20.42
	Rio Grande NF	563.8	25.10	28.28	14.28
	San Juan NF	1064.7	23.43	25.97	15.80
	White River NF	301.5	34.88	30.84	15.24
	Apache-Sitgreaves NF	949.5	25.77	26.31	14.51
R3: Southwestern	Cibola NF	720.9	24.53	30.39	17.28
	Coconino NF	841.3	29.12	30.41	18.03
	Coronado NF	662.8	45.29	34.21	19.63
	Gila NF	173.0	14.81	26.95	17.05
	Kaibab NF	806.8	16.93	31.74	17.97
	Lincoln NF	228.0	41.07	30.94	18.90
	Prescott NF	822.6	16.04	32.87	24.74
	Santa Fe NF	487.4	22.36	29.69	18.29
	Tonto NF	469.8	12.16	24.15	14.96
	Ashley NF	1972.1	9.71	27.90	20.21
R4: Intermountain	Boise NF	315.5	17.38	25.53	13.75
	Dixie NF	463.5	14.97	25.25	16.04
	Eldorado NF	526.1	24.82	28.54	17.95
	Fishlake NF	524.9	15.73	30.82	20.93
	Humboldt-Toiyabe NF	1188.8	14.05	31.14	19.07
	Inyo NF	287.0	41.90	29.82	17.19
	Lake Tahoe Basin MA	507.8	33.12	32.15	19.91
	Manti-La Sal NF	397.8	26.16	32.27	19.07
	Sawtooth NF	399.3	21.02	33.11	24.29
	Stanislaus NF	600.6	15.79	26.74	15.07
R5: Pacific Southwest	Tahoe NF	28.4	45.16	57.17	44.66
	Uinta-Wasatch-Cache NF	982.5	8.84	32.08	24.38
	Angeles NF	975.2	18.52	27.56	17.23
	Cleveland NF	710.3	13.04	24.30	15.77
	Lassen NF	764.0	5.34	22.15	15.09
	Los Padres NF	945.1	20.98	29.02	16.66
	Mendocino NF	534.3	37.50	36.66	21.00

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Region	National Forest Unit	Total USFS-owned wild. veg. area within 500 m of inholdings (km ²)	% area < 500 m from a building	% area < 250 m from a building	% area < 100 m from a building
R6: Pacific Northwest	Plumas NF	315.6	34.25	31.42	19.00
	San Bernardino NF	956.2	17.67	29.58	18.62
	Sequoia NF	431.1	47.62	38.00	21.92
	Shasta-Trinity NF	332.7	22.91	25.14	15.94
	Sierra NF	517.7	31.97	35.12	21.23
	Columbia River Gorge NSA	587.2	18.60	30.29	19.73
	Deschutes NF	107.6	44.88	38.37	18.45
	Fremont-Winema NF	341.5	14.01	22.82	13.13
	Gifford Pinchot NF	319.8	30.82	35.88	22.00
	Klamath NF	988.4	5.81	26.19	14.96
	Malheur NF	81.2	25.39	34.29	18.02
	Modoc NF	498.4	8.43	18.68	12.27
	Mt. Baker-Snoqualmie NF	410.9	20.19	32.52	17.88
	Mt. Hood NF	57.8	22.26	34.83	23.02
	Ochoco NF	380.3	18.68	31.29	20.91
	Okanogan-Wenatchee NF	973.0	27.17	29.09	15.81
	Olympic NF	233.4	19.88	29.50	15.68
	Rogue River-Siskiyou NF	559.7	14.90	25.96	15.36
	Siuslaw NF	397.3	24.62	26.93	14.04
	Six Rivers NF	255.0	9.17	21.76	13.40
R8: Southern	Umatilla NF	227.9	15.06	22.47	11.38
	Umpqua NF	502.2	12.84	22.56	12.67
	Willamette NF	324.5	16.11	32.89	20.61
	Chattahoochee-Oconee NF	692.5	39.13	31.20	15.63
	Cherokee NF	85.2	34.28	29.93	16.94
	Daniel Boone NF	1407.0	40.15	32.56	17.38
	Francis Marion and Sumter NF	1157.6	29.76	29.29	14.72
	George Washington and Jefferson NF	1837.0	32.33	28.02	15.64
	Hoosier NF	1089.8	30.85	29.99	14.32
	Kisatchie NF	4.8	21.59	23.42	11.85
	Land Between the Lakes NRA	1147.0	24.44	25.66	13.47
	Mark Twain NF	626.9	48.23	35.92	18.33
	Monongahela NF	2572.8	30.79	26.34	13.11
	NFs in Alabama	754.6	38.24	34.58	18.24
	NFs in Florida	328.7	43.82	30.20	14.75
	NFs in Mississippi	2206.2	27.01	25.71	13.14
	NFs in North Carolina	1543.7	29.90	22.57	11.00
	NFs in Texas	678.6	39.13	30.31	14.79
	Ouachita NF	2056.3	28.13	24.13	12.93
R9: Eastern	Ozark-St. Francis NF	1627.8	31.47	27.13	18.31
	Shawnee NF	651.4	35.52	30.58	16.17
	Allegheny NF	1152.9	32.04	24.37	14.43
	Chequamegon-Nicolet NF	635.9	48.81	28.58	12.78
	Chippewa NF	2265.1	45.00	29.80	13.76
	Green Mountain and Finger Lakes NF	3678.9	31.93	25.28	16.77
	Hiawatha NF	13.9	38.02	29.55	17.62
	Huron-Manistee NF	823.4	27.94	26.38	14.21
	Midewin NTP	385.5	20.71	19.69	11.54
	Ottawa NF	878.5	36.15	25.47	11.85
	Superior NF	3631.6	13.27	24.71	17.67
	Wayne NF	843.3	54.28	31.44	14.01
	White Mountain NF	486.3	30.68	30.16	17.79

Appendix G. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.landurbplan.2023.104810>.

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