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A Baseline Land Use Map for the Conterminous United States

A Technical Document Supporting the
USDA Forest Service 2020 RPA Assessment

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ABSTRACT

Projecting land use transitions onto a wall-to-wall raster requires an initial basemap of land use for the projection period. The 2020 Resources Planning Act (RPA) Assessment includes spatial realizations of county-level land use projections; these realizations are a collection of 90-meter resolution rasters that allocate the county-level projections across the conterminous United States (CONUS). The 2020 basemap is a 90-meter raster depicting land use across the CONUS circa 2020 and is used as the starting position for the spatial realizations. The basemap was created by fusing a modified land cover map with a forest land use map, then constraining forest land area to match area estimates per State using the RPA definition of forest. The 2020 basemap rasterizes land use for the starting year of the 2020 RPA Assessment while using the same land use classes as the county-level projections, and its forest land area totals per State are consistent with forest inventory estimates used in other parts of the RPA Assessment. The basemap also showed good agreement on per-State forest area estimates when compared to the 2017 Forest Resources Report. A 2011 basemap was generated using similar methods, providing two points in time for researchers to model dynamic processes.

KEYWORDS: Land use map, RPA Assessment, forest land, landscape, spatial realizations, map fusion.

INTRODUCTION

Land use (LU) and land cover (LC) maps are critically important for understanding the landscape, its spatial patterns and configurations, and the impacts of natural and anthropogenic drivers on that landscape. Land use is a function of the social and economic purposes of the land, while land cover is based on observed biological cover (Coulston et al. 2013). Clearly land use and land cover are not identical: for example, a forest (LU) may be harvested via a clearcut before replanting, temporarily removing most vegetation and converting it to barren ground (LC) while still retaining its forest use. Thus, maps of both land use and land cover are important descriptors of landscape status and trends.

The Resources Planning Act (RPA) 2020 Assessment (USDA Forest Service 2023) projects the current non-Federal land base of the conterminous United States (CONUS) from 2020 to 2070 by incorporating modeled future climate and socioeconomic attributes into additional models which describe landscapes and ecological systems within the present-day CONUS. In particular, future land use projections at the county level are derived from an econometric model (Mihiar and Lewis 2023), then allocated to a 90 m raster of the CONUS via a hybrid algorithm (Brooks et al. 2020). In the second step, the changes from the county-level model are

translated to raster form, but changes must be applied to a consistent basemap depicting land use circa 2020. The land use basemap must be consistent with the thematic resolution (i.e., have the same land use classes) of the county-level projections and align with land use definitions from the RPA Assessment. We describe here the generation of the 2020 land use basemap.

METHODS

The land use projections of the 2020 RPA Assessment are generated by models which were estimated from observed status and trends in the National Resources Inventory (NRI) plot data (Mihiar and Lewis 2023). The land use projections are given for broad classes based on the original NRI classes (table 1). For consistency with the land use projections, we constrained our basemap to the same classes. However, for consistency with forest land use area estimates from the U.S. Department of Agriculture, Forest Service, Forest Inventory and Analysis (FIA) program, the structure of which (e.g., a collection of projected future forest inventories) is used in other parts of the 2020 Assessment (Coulston et al. 2023), we harmonized forest area estimates with those derived from FIA for the RPA Assessment. The overall framework is depicted in figure 1; details for each dataset and processing steps follow in this section.

Table 1—First-order translation of National Land Cover Dataset (NLCD) land cover classes to 2020 basemap classes, which are in turn based on National Resource Inventory (NRI)-based land use classes

NLCD classes	2020 basemap classes	NRI classes
11	Water	Small water areas; large water areas
21, 22, 23, 24	Developed	Urban and built-up land
41, 42, 43, 90	Forest	Forest land
12, 31, 51, 52, 71, 72, 73, 74, 95	Other natural	Rangeland; minor land; rural transportation; Federal land; conservation reserve program (CRP)
81	Pasture	Pastureland
82	Crop	Cultivated cropland; noncultivated cropland

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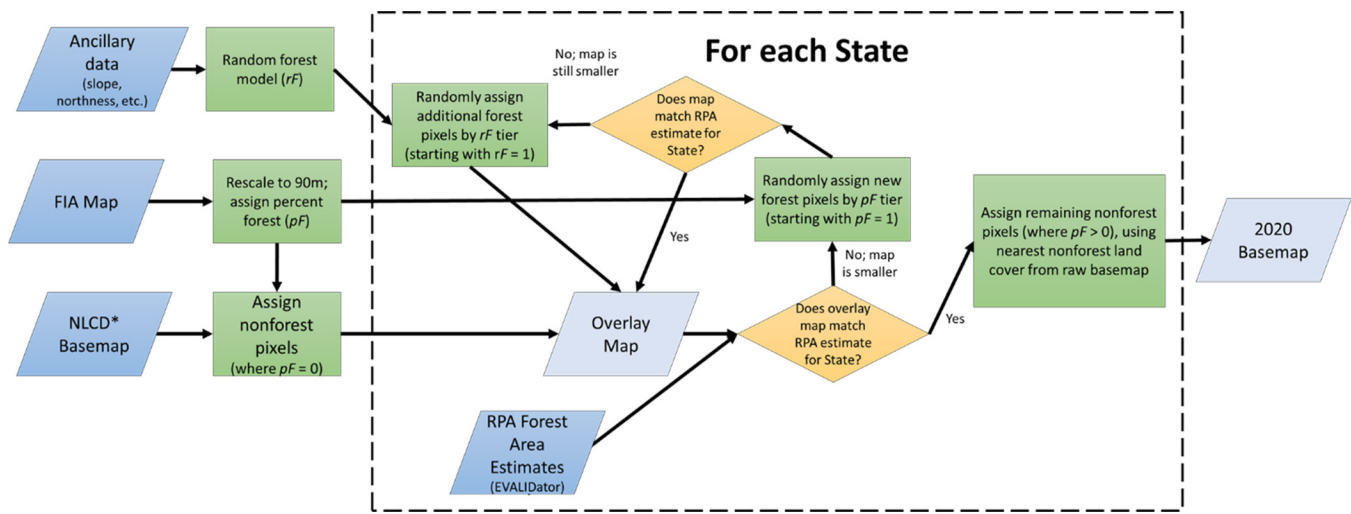


Figure 1—Spatial modeling process to generate the 2020 basemap.

Forest land is defined by FIA as land comprising an area of at least 1 acre (0.4 ha) and a width of 120 feet (37 m), with live tree cover of at least 10 percent (stocking included, per the definition). Forest land includes land which formerly had tree cover and will be naturally or artificially regenerated; forest land use may not currently have forest land cover. Lastly, trees in the forest must be capable of achieving a diameter at breast height of at least 3 inches (7.6 cm), or 5 inches (12.7 cm) diameter at root collar. However, forest land as defined by the RPA Assessment has the additional requirement that trees should be capable of reaching a mature height of 16.4 feet, 5.0 m (Coulston et al. 2016). This is because RPA uses the definition for forests given by the Food and Agriculture Organization to facilitate international reporting. RPA forests thus constitute a subset of FIA forests, so the RPA forest area estimates are always bounded above by corresponding FIA forest area estimates. For our purposes, we summarized RPA-defined forest area estimates circa 2017 by U.S. State (hereafter, State) using the Forest Service EVALIDator online tool (USDA Forest Service 2019) for the most recent available data at the time, which varied by the State.

While land cover and land use are different, they are often related (Coulston et al. 2013); thus, we started with the 2016 National Land Cover

Database (NLCD) which was the most recent version of the NLCD product at the time (Dewitz 2019). We reclassified the NLCD raster classes to match our target land use classes (table 1), which were in turn largely based on NRI land use classes. Because NLCD is in effect a combined use/cover product approximating the Anderson level II classification, some nonforest land uses (e.g., crop, pasture, and developed) were identifiable with their corresponding covers; we preserved these classes as given by the NLCD map. The majority of the remaining nonforest land uses, including rangeland, were aggregated into the “Other Natural” class of the RPA land use projections.

For forest land use, we considered four cases: 1) nonforest land use on nonforest land cover, 2) nonforest land use on forest land cover, 3) forest land use on forest land cover, and 4) forest land use on nonforest land cover. Reasoning and assignments for case 1 were given in the previous paragraph. For case 2, such as tree cover in residential areas, we had no feasible way to identify these lands other than as forest land use, with the justification that by eventually rescaling the NLCD map to 90 m resolution, the majority of such lands would likely be absorbed into neighboring nonforest land use classes per the contextual NLCD map. Case 3 represents the most convenient case; in light of our approach to

case 2, we assigned forest land cover as forest land use, similar to our initial assignment of nonforest classes in case 1 in the previous paragraph. Thus, our primary modification to the NLCD map toward land use involved case 4, where forest land use is on nonforest cover. One way this can occur is on forest land post-harvest, where the cover would reflect the successional state. From a land cover perspective, this might appear as grassland or shrubland (Anderson classes 71 and 52, respectively), but some prior record of forest cover was necessary to justify reassigning such pixels. Thus, we used NLCD products from 2006 and 2011 (Fry et al. 2011, Homer et al. 2015) in a process identical to that of Brooks et al. (2020); pixels of grassland and shrubland in the NLCD 2016 map were assigned as forest land use only if for at least one of 2006 and 2011, the same pixels were assigned a forest land cover and all other assignments through time were also grassland or shrubland. For example, a pixel labeled as forest cover in 2006 but as grass in 2011 and shrub in 2016 would be reclassified as forest land use. Unlike our treatment of the other three cases for forest land use and cover, this approach altered the map; we designated this modified map of land use for 2016 as the NLCD* map. This approach reduced the mapped area of grassland and shrubland, accordingly.

The reasoning underlying the NLCD* map is similar to the FIA definition of forest land use as being currently nonforested land which is not developed for another land use (Bechtold and Patterson 2005), but the overall forest area estimated by the NLCD* map (617 million acres for the CONUS) was less than the corresponding RPA estimate (638 million acres for the CONUS). Thus, we needed to address other possible, less easily addressable causes for forest land to have nonforest cover. To do this, we incorporated an existing, independently-generated map of FIA-defined forest land use circa 2011, denoted hereafter as the FIA map (Nelson et al. 2009a). The FIA map was generated from a combination of land cover products, FIA-based State forest area estimates and site productivity, and Gap Analysis

Program (GAP) status from the Protected Areas Database (Gergely and McKerrow 2016, USGS 2021), using the methods found in Nelson et al. (2009a). The FIA map estimates CONUS forest area to be 632 million acres, still less than the RPA estimate, but more than the NLCD* map estimate. It has a 30 m resolution, so we rescaled it to the 90 m resolution of the NLCD* map, then assigned pixels a “percent forest” value from 0 to 1, with those values being the number of 30 m forested pixels divided by 9 (e.g., a 3 x 3 window at 30 m with 5 forested pixels would have a 90 m value of 0.56). This converted the FIA map into a pseudo-probability map of forest LU, based on the FIA definition of forest. Applying an average-based percent forest instead of a majority-based forest/nonforest reclassification reduces artifacts of spatial aggregation (Nelson et al. 2009b).

The NLCD* map is based on the 2016 NLCD product data, but the FIA map is based on 2011 NLCD product data. It is thus possible for forest land in 2011 (seen in the FIA map) to become nonforest land by 2016 (and be nonforest in the NLCD* map, or potentially nonforest cover but still forest land use). Additionally, data processing differences between the 2011 and 2016 NLCD products might alter pixel classifications between the years, regardless of the land condition. However, since the FIA map generally included more forest land use area than the per-State RPA estimates being targeted (fig. 2), we converted such pixels to nonforest in the NLCD* map, assigning to them the most prevalent nonforest land use class from their local neighborhoods. This approach reduced the utility of the NLCD* map for pixel-specific analyses (likewise, the final product), but it improved the consistency of the map with RPA estimates at coarser scales.

With the NLCD* map and FIA map preprocessed, we next overlaid these two rasters (fig. 3), while constraining the overall per-State forest area to the RPA forest estimates. To do this, we first preserved all pixels from the NLCD* map for which the FIA map showed nonforest (that is, 90 m pixels with a percent forest value of 0). Then, starting with

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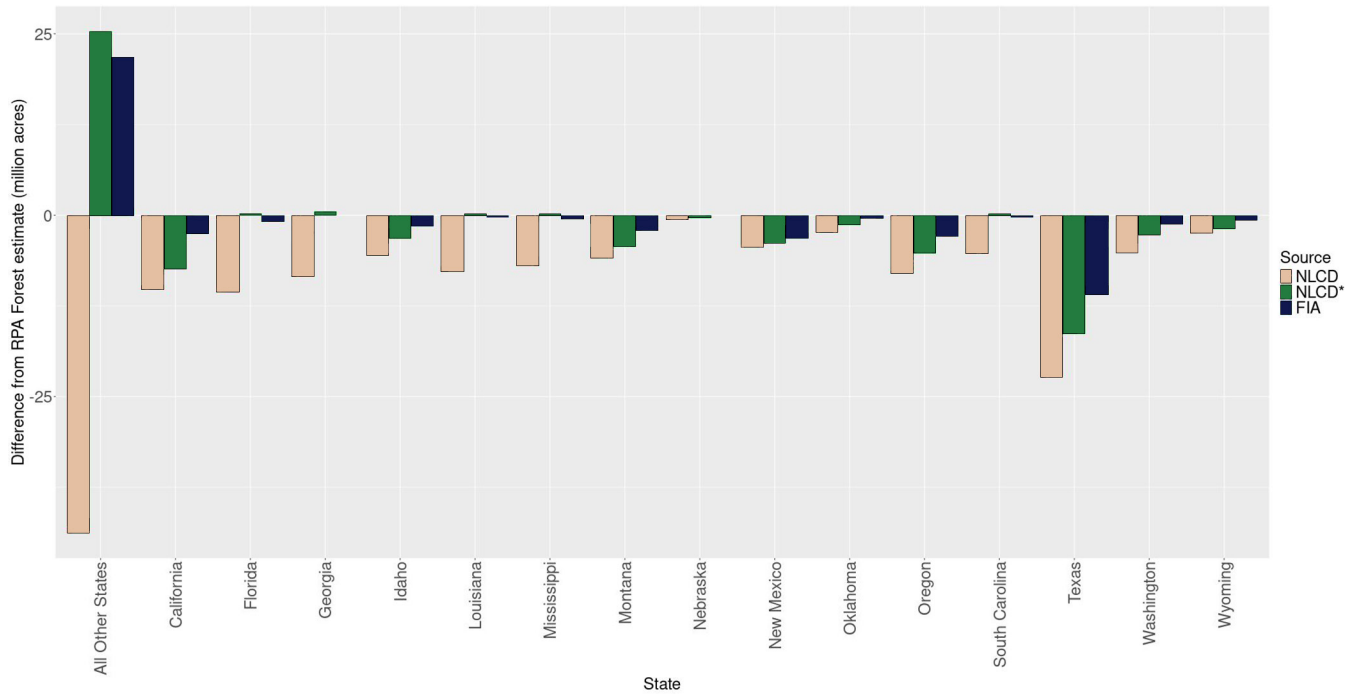


Figure 2—Comparison of forest areas between the National Land Cover Dataset (NLCD) map, NLCD* map, and Forest Inventory and Analysis (FIA) map, by State. Values are given with respect to difference from the corresponding Resources Planning Act (RPA) forest area estimates. Only States for which the FIA map estimated less forest area than the RPA estimate are individually shown.

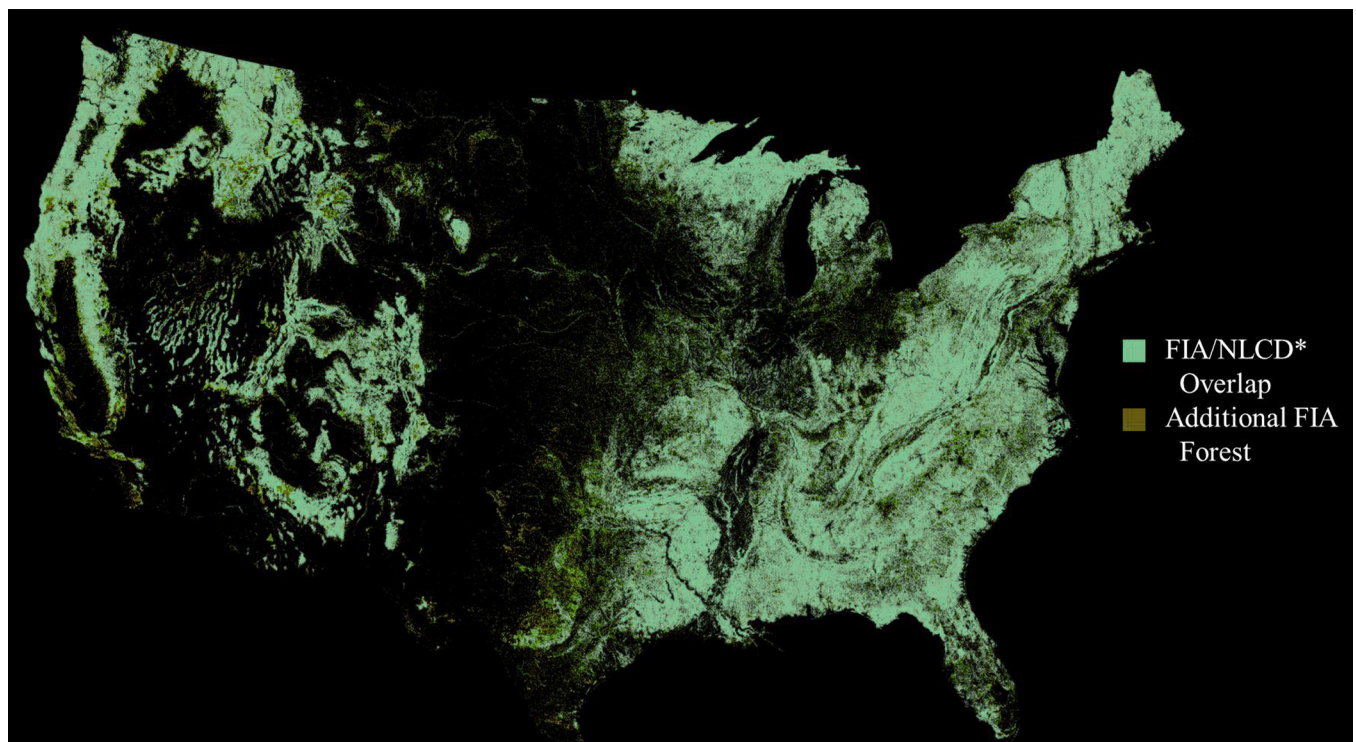


Figure 3—Overlay Of the NLCD* and FIA maps. The case where the NLCD* map assigned forest, but the FIA map did not, is not shown because it represents too small an area to be seen at this scale.

NLCD* pixels with the highest corresponding percent forest values from the FIA map, we assigned forest pixels to the resulting overlay map. To avoid systematic or spatial biases, we assigned forest pixels randomly within the distribution of percent forest for ties: for example, while all pixels with percent forest value 1 were assigned as forest before pixels with value 0.89, the spatial order in which those pixels were assigned was randomized; similarly, all pixels with a percent forest value of 0.89 would be assigned before randomizing pixels with a percent forest value of 0.78. Thus, when the within-State forest area on the overlay map reached the RPA forest area estimate (and thus no more pixels were assigned to forest land use), there was no arbitrary concentration of forest in any one place in the State. We did this on a State-by-State basis. When the target forest area was reached for each State, any remaining pixels (that is, pixels with a percent forest value greater than 0 but not assigned forest by the above process) were assigned a nonforest land use class. Where the NLCD* map gave a nonforest class, we used that value. Where the NLCD* map gave forest, we assigned the nearest nonforest land use instead. This area was relatively small, approximately 1 percent of the forest area covered by the two maps.

In some States, the 2017-based RPA forest area estimate exceeded the FIA map area (fig. 2). In some cases, such as States in the Southeastern United States, this was likely due to changing forest area from 2011 (the basis year for the FIA map) to 2017. But in States in the Western United States, the FIA definition of forest was expanded to include sparse woodlands, producing spikes in forest area estimates for Western States in general. This definitional change occurred after the FIA map was created, so it cannot account for the new forest area estimates. Stretching the FIA map to allow for 90 m pixels with 0.11 forest probability values (i.e., 90 m pixels for which only one of the nine 30 m pixels was forest) made up much of this difference, but in two States, Texas and New Mexico, there were still insufficient forest pixels to draw from. To address this, we made a simple

random forest (*rF*) model (Breiman 2001). A *rF* model is a nonparametric model that generates multiple classification or regression trees by sampling with replacement from a collection of explanatory and response variables. Our response was a likelihood of a pixel being forest (training data were based on the FIA map and NLCD* map overlay); our explanatory variables included but were not limited to rangeland (Reeves and Mitchell 2011), slope/elevation, northness, harmonic regression coefficients (Brooks et al. 2012) based on rescaled MODIS remote sensing data, percent land use, and protected area status to predict the likelihood of any pixel in the CONUS in being forest. When we exhausted the available pixels from the FIA map for a given State (i.e., Texas and New Mexico), we assigned additional pixels to forest according to the *rF* model until the assigned area matched the RPA estimate for that State. The resulting overlay map is the basemap used in the 2020 RPA Assessment, referred to as “the 2020 basemap.”

We also made a companion basemap for the 2011 year, in support of the broader RPA Assessment, as some resource areas required multiple years of consistent basemaps to make empirical models such as impervious cover projections for urban forestry (Riitters et al. 2023). We adjusted maps for a “once-water, always water” rule, as well as ensuring 2011 development was also present on the 2020 map to harmonize with a “once-developed, always-developed” assumption in the land use projection models. The final 2020 basemap reflects these adjustments, for consistency of comparison between RPA resource areas.

RESULTS AND DISCUSSION

The 2020 basemap (fig. 4) is a wall-to-wall raster map of land use for the CONUS, with per-State forest area matching that for the RPA-defined forest land use. With the exception of rangeland, it includes all the land use classes used in the land base chapter (Riitters et al. 2023) of the 2020 RPA

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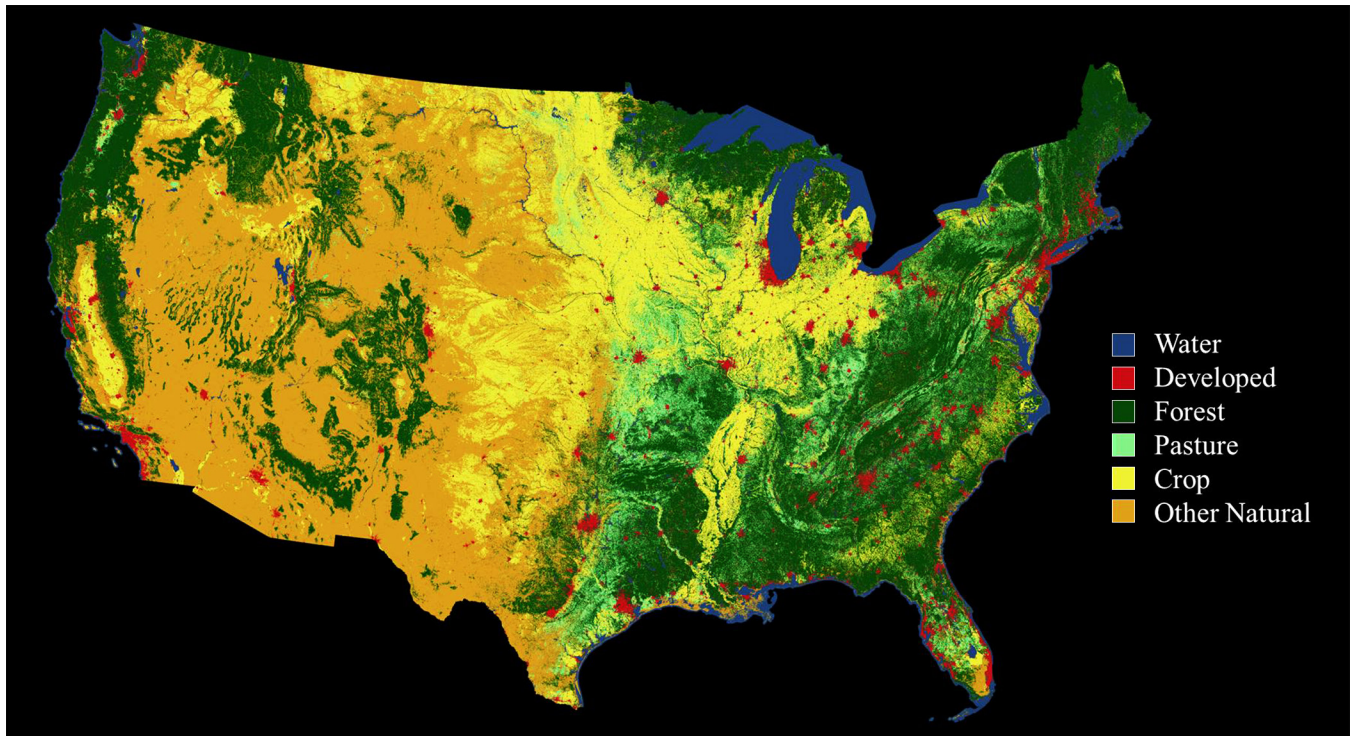


Figure 4—Resources Planning Act (RPA) 2020 basemap, a 90 m raster of land use for the conterminous United States.

Assessment. Unlike forest land use, there was not sufficient information to distinguish rangeland as a separate class; thus, in the 2020 basemap rangeland is treated as a subset of the Other Natural land use class. This map is used within the RPA Assessment whenever a 2020 or starting-condition map is needed for land use projections and analysis (Riitters et al. 2023), for forest dynamics and assignment of forest attributes at a sub-county level (Coulston et al. 2023), and other uses such as aquatic species biodiversity (Bury et al. 2021). By establishing a common baseline for the RPA library of spatial realizations of land use projections, the 2020 basemap serves as a foundation for interpretation of projected changes to the CONUS land base.

The methods we used, namely that of using a percent forest map to guide random assignment of forested pixels, are similar to those of He et al. (1998). In that work, He used a guided allocation process to assign age and species classes to forested pixels, using ecoregion boundaries

(Host et al. 1996). For our basemap, we used State boundaries to facilitate comparison to the 2020 RPA Assessment (itself using geopolitical boundaries for most analyses), but future basemaps could incorporate ecoregion or other natural-feature based partitions to better inform pixel assignments.

We designated the basemap year as 2020 to facilitate analyses within the RPA Assessment. However, the land cover data used for the raw basemap are from 2016, and the forest LU map was based on 2011 NLCD data. Additionally, the RPA-defined forest area estimates per State are based on the most recent available data at the time, not necessarily the same year per State. These discrepancies introduce variability into the estimates. However, comparing the basemap with the 2017 Forest Resources Assessment (Oswalt et al. 2019), another supporting document for the 2020 RPA Assessment, shows good agreement between the map-based and plot-based forest area estimates by State (fig. 5).

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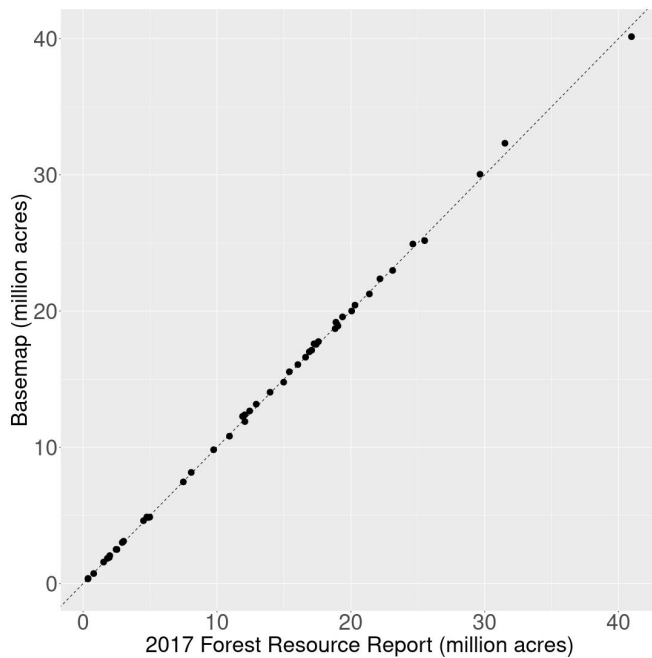


Figure 5—Comparison of State-level forest areas (RPA definition) between the 2017 Forest Resources Report and the RPA 2020 basemap. Dots represent individual States; the dashed line is the identity line.

We made slight changes to the 2020 basemap in the process of harmonizing it with the 2011 basemap (see Methods section), with the intent of keeping both water and developed pixels in place from the 2011 map to the 2020 map. This altered pixels and likely reduced the overall map accuracy, but it allowed users to track per-pixel changes while maintaining assumptions about stable water and permanent conversion to developed pixels.

Ultimately, the 2020 basemap is the result of incorporating many different (and often, disparate) landscape maps. The input maps used were of different landscape properties (cover and use) and were drawn from different years of data acquisition. There was a procedural change for the FIA definitions of forest land that impacted interpretation of the FIA map. Not least, the land use classes for the resulting basemap were based on modified NRI classes.

Effectively, the 2020 basemap represents our best attempt to harmonize these inputs into a consistent baseline for the spatial realizations and other RPA-based analyses. Future iterations of the basemap would benefit greatly from having more consistent input data, particularly using FIA-based land use definitions across the board. Refinements to future NLCD products, such as the “transitional forest” classes used in the NLCD 2021 product (Dewitz 2023), would also help reduce the definitional discrepancy between NLCD and FIA (and thus RPA) definitions. These additional classes have been retroactively applied to prior years of NLCD products, as well; they employ similar reasoning to our approach in generating the NLCD* map used in this work.

CONCLUSIONS

The 2020 basemap supports a variety of RPA Assessment goals. It serves as the basis for the spatial realizations of county-level land use projections out to 2070 (Brooks et al. 2023). In conjunction with its 2011 basemap, it enables spatially-explicit model training (Bury et al. 2021, Riitters et al. 2023). It also enables spatial imputation of forest inventory attributes, both for the current inventory and future projections (Coulston et al. 2023). Being a map of land use, it does not directly compare with land cover maps, but it could be used to translate projected changes of land cover into a projected land use change context. As data are updated, the basemap and its generation process will be updated and refined in support of the RPA 2030 Assessment. The 2020 basemap is available for download, as are the spatial realizations of county-level land use projections derived from the 2020 basemap, via the USDA Forest Service Research Data Archive (Brooks et al. 2023).

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Projecting land use transitions onto a wall-to-wall raster requires an initial basemap of land use for the projection period. The 2020 Resources Planning Act (RPA) Assessment includes spatial realizations of county-level land use projections; these realizations are a collection of 90-meter resolution rasters that allocate the county-level projections across the conterminous United States (CONUS). The 2020 basemap is a 90-meter raster depicting land use across the CONUS circa 2020 and is used as the starting position for the spatial realizations. The basemap was created by fusing a modified land cover map with a forest land use map, then constraining forest land area to match area estimates per State using the RPA definition of forest. The 2020 basemap rasterizes land use for the starting year of the 2020 RPA Assessment while using the same land use classes as the county-level projections, and its forest land area totals per State are consistent with forest inventory estimates used in other parts of the RPA Assessment. The basemap also showed good agreement on per-State forest area estimates when compared to the 2017 Forest Resources Report. A 2011 basemap was generated using similar methods, providing two points in time for researchers to model dynamic processes.

KEYWORDS: Land use map, RPA Assessment, forest land, landscape, spatial realizations, map fusion.



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