AGU ADVANCING EARTH AND SPACE SCIENCES

Earth's Future

REVIEW ARTICLE
10.1029/2025EF007467

Current Status, Past Trends, and Future Projections of Renewable Forest Resources and Ecosystem Services Across the United States

Travis Warziniack[1], Jennifer K. Costanza[2], Rebecca L. Flitcroft[3], Linda A. Joyce[1], Christoper Mihia[2], Claire O'Dea[4], Sonja N. Oswalt[5], Jeffrey P. Prestemon[2], and Eric White[6]

[1]USDA Forest Service, Rocky Mountain Research Station, Fort Collins, CO, USA, [2]USDA Forest Service, Southern Research Station, Durham, NC, USA, [3]USDA Forest Service, Pacific Northwest Research Station, Corvallis, OR, USA, [4]USDA Forest Service, Washington Office, Washington, DC, USA, [5]USDA Forest Service, Southern Research Station Forest Inventory and Analysis, Knoxville, TN, USA, [6]USDA Forest Service, Pacific Northwest Research Station, The Dalles, OR, USA

Key Points:

- Changes in land use, combined with climate change, are leading to habitat fragmentation, loss of biodiversity, and altered ecosystems
- The interactions between climate change and disturbances such as wildfires are creating a mosaic of high-stress areas throughout the U.S.
- Climate and socioeconomic factors increase intensity and duration of water shortages and influence future roundwood markets

Supporting Information:

Supporting Information may be found in the online version of this article.

Correspondence to:

T. Warziniack,
travis.warziniack@usda.gov

Citation:

Warziniack, T., Costanza, J. K., Flitcroft, R. L., Joyce, L. A., Mihia, C., O'Dea, C., et al. (2026). Current status, past trends, and future projections of renewable forest resources and ecosystem services across the United States. *Earth's Future*, *14*, e2025EF007467. https://doi.org/10.1029/2025EF007467

Received 6 OCT 2025
Accepted 11 MAY 2026

Author Contributions:

Conceptualization: Travis Warziniack, Rebecca L. Flitcroft, Linda A. Joyce, Christoper Mihia, Claire O'Dea, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White
Data curation: Sonja N. Oswalt, Jeffrey P. Prestemon
Formal analysis: Travis Warziniack, Rebecca L. Flitcroft, Linda A. Joyce, Christoper Mihia, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White
Investigation: Christoper Mihia, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White

Abstract Forest ecosystems provide essential services such as timber, water regulation, biodiversity, and recreation, yet they are increasingly influenced by the interplay between climate and socioeconomic forces. This study synthesizes findings from the 2020 Resources Planning Act (RPA) Assessment to evaluate how these factors affect historical trends and future projections of U.S. forest conditions and services. Results show that total forest area is projected to decline slightly by 2070, mainly due to conversion to developed land, with the greatest losses occurring in the South. While socioeconomic factors such as population growth, income, and land-use markets dominate near-term changes in forest area, timber demand, and recreation, climate change has a larger impact on disturbance patterns, water availability, and forest productivity, particularly under higher warming scenarios. Although overall net changes in forest area are small, land cover data reveal significant losses in interior forests, emphasizing the importance of spatial patterns for biodiversity and ecosystem health. These results illustrate that future forest outcomes depend on the interaction of economic and environmental processes, informing region-specific management and policy strategies.

Plain Language Summary This paper summarizes recent trends and future projections of U.S. forests using results from the 2020 Resources Planning Act Assessment. We show that while total forest area is expected to change only modestly, where forests are located and how they function will shift substantially. Population growth and land development are the primary drivers of forest loss, especially in the South, while climate change is increasingly affecting wildfires, drought, and water availability. These combined pressures are expected to fragment habitats, reduce interior forest cover, and alter the ecosystem services forests provide, with important implications for management and policy.

1. Introduction

Forests supply essential ecosystem goods and services, support human health and well-being, and are crucial for nature-based solutions to climate change (Bonan, 2008; Domke et al., 2023; Foley et al., 2005). In the U.S., forests make up 34% of the land area, sequester 45.5 billion metric tons of carbon annually, and provide 39% of the nation's water (Coulston, Brooks et al., 2023; Oswalt et al., 2019; Warziniack et al., 2023). Although the total forest area has increased slightly over recent decades (Oswalt et al., 2019), several factors threaten the benefits forests offer. There has been a net loss of interior forest land cover due to land-use changes and disturbances (Riitters et al., 2023), which has significantly reduced local biodiversity (Newbold et al., 2015). During the same period, wildfires grew in size and severity (Costanza, Koch, Reeves, et al., 2023; Costanza, Koch, Reeves, 2023), and forests became more vulnerable to insect damage and storms. These factors impact forests' ability to store carbon, produce timber and non-timber products, sustain aquatic and terrestrial ecosystems, and supply the quantity and quality of water the nation depends on (Crimmins et al., 2023; USGCRP, 2018; Weiskopf et al., 2020). Many of these trends are expected to persist as a warming climate changes precipitation patterns, influencing the frequency of wildfires, disease outbreaks, windthrow, and other disturbances. These combined disturbances, along with ongoing land-use changes, are likely to reduce some forests' capacity to regenerate and maintain their current structure and composition, thereby affecting the ecosystem services they provide.

Methodology: Travis Warziniack, Rebecca L. Flitcroft, Linda A. Joyce, Christoper Mihia, Claire O'Dea, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White
Project administration: Travis Warziniack, Claire O'Dea
Resources: Travis Warziniack, Rebecca L. Flitcroft, Claire O'Dea
Supervision: Travis Warziniack, Claire O'Dea
Visualization: Jeffrey P. Prestemon, Eric White
Writing – original draft: Travis Warziniack, Rebecca L. Flitcroft, Linda A. Joyce, Christoper Mihia, Claire O'Dea, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White
Writing – review & editing: Travis Warziniack, Rebecca L. Flitcroft, Linda A. Joyce, Christoper Mihia, Claire O'Dea, Sonja N. Oswalt, Jeffrey P. Prestemon, Eric White

The US Forest Service evaluates current forest health, future forest availability and conditions, and forests' capacity to deliver essential ecosystem services through the Resources Planning Act (RPA) Assessment. This assessment, mandated by the Forest and Rangeland Renewable Resources Planning Act of 1974, was established by Congress to address concerns about resource scarcity and support America's competitiveness in natural resource industries. The 2020 RPA Assessment, the latest version, is a comprehensive, multi-year project involving dozens of scientists from various Forest Service research stations (USDA, 2023; hereafter "RPA Assessment"). Its focus areas include forest resources (such as area, condition, removals, and carbon), forest products, outdoor recreation, biodiversity, and water resources. It is distinguished by its broad scope and in-depth analysis.

Because of its breadth and technical complexity, the full 2020 RPA Assessment report is nearly 350 pages long and targets resource managers, planners, and policy specialists familiar with the Assessment's history and methods. While the decadal report is the primary deliverable, the RPA Assessment also functions as an ongoing, multidisciplinary research program. Each research topic is developed through an extended research cycle, generating numerous products that are not always integrated across different areas. This paper, therefore, aims to make the RPA Assessment's findings more accessible to a broader scientific audience and to synthesize insights across resource areas, which the chapter-structured full report does not do. A central contribution of this work is to evaluate how climate and socioeconomic drivers interact to shape forest ecosystem services across sectors, regions, and time horizons. The authors of this manuscript contributed to the 2020 RPA Assessment; however, this paper represents a distinct synthesis and interpretation of those results.

A key tenet of the RPA Assessment is its view of forests as social-ecological systems (Cutter et al., 2009; O'Neill et al., 2014; Riahi et al., 2017; Sanchez, Warziniack, and Knowles, 2023; Warziniack et al., 2024), and it is the only national assessment we know of that considers both climate and socioeconomic drivers of change and their impacts on renewable resources. The Assessment covers, for example, interactions between the country's large, active timber market and changes in forest structure caused by disturbances and active management. It also evaluates forests of all ownership types—roughly 58% of U.S. forestland is privately owned and increasingly part of a mosaic of other land uses (Oswalt et al., 2019). In the recreation assessment, socioeconomic factors such as population growth and income directly influence participation levels and rates, and climatic variables such as extreme temperature and reduced snowpack availability affect activities like skiing. These socioeconomic drivers can intensify and sometimes surpass the effects of climate drivers on forests.

The RPA Assessment uses a common scenario framework, enabling direct comparison of expected outcomes across different possible futures. Future forest area and conditions are projected across four scenarios that combine global Representative Concentration Pathways (RCPs) with Shared Socioeconomic Pathways (SSPs), each evaluated under five global climate model projections that capture the expected range of temperature and precipitation changes for the conterminous United States (see Methods; Figure 6; Figure A1 in Supporting Information S1). These scenarios provide a basis for understanding how socioeconomic and climate factors may interact over time to shape various natural resource futures, both qualitatively and quantitatively. Scenarios are not assigned probabilities; instead, they serve as a foundation for objectively assessing a plausible range of future resource outcomes. This method is especially useful given the uncertainties surrounding political, economic, social, and ecological paths (Alcamo et al., 2003).

2. Results

This paper begins by highlighting recent trends in forest area and condition, then proceeds to projections of the impacts of these trends on services provided by forest-dependent ecosystems. Recent studies show that although the total forested land in the U.S. has remained stable, there is significant movement of land between forest and non-forest uses (Oswalt et al., 2019; Riitters et al., 2023). These changes in forest cover, along with climate change and forest disturbances, lead to habitat fragmentation, biodiversity loss, and disruption of ecosystem processes. These stressors suggest a future in which forests may not regenerate as they once did, thereby jeopardizing the availability of forest-dependent ecosystem services.

2.1. Recent Trends and Projections of Forest Area and Conditions

Despite urban expansion, increased fragmentation, and growth of the wildland–urban interface (WUI), the United States experienced a net increase of about 2% in total forestland between 1990 and 2010 (Oswalt et al., 2019). During this period, urban growth expanded the WUI in the conterminous U.S. by 46.8 million acres (Radeloff et al., 2018), incorporating 20 million acres of existing forest land into the WUI (Riitters et al., 2023). This net increase in forest area was driven primarily by the conversion of pasture to forest, with approximately 20 million acres transitioning between 1982 and 2012, as documented in the USDA National Resources Inventory (USDA, 2015). These gains more than offset forest losses to development and other land uses (Figure A2 in Supporting Information S1). Consistent with broader land use trends, these transitions occurred predominantly in the eastern United States, where declining agricultural land use and structural changes in land markets facilitated forest regrowth.

While land-use statistics suggest relative stability in forest area, land-cover data reveal a different pattern. Estimates from the National Land Cover Database (NLCD) indicate a net loss of 2.6% of forest cover in the conterminous United States between 2001 and 2016 (Riitters et al., 2023). This difference reflects a fundamental distinction between land use and land cover. RPA land use data, derived from the National Resources Inventory (USDA, 2015), track administrative land use categories (e.g., forestland, cropland, developed) and reclassify land only when its primary use changes. In contrast, the NLCD uses satellite imagery to measure actual land cover, capturing within-category changes such as thinning, partial clearing, and fragmentation that do not trigger land use reclassification. As a result, land use statistics may indicate stability in total forest area, while land cover data reveal ongoing losses in forest extent and connectivity.

These differences are particularly important for understanding ecological function. The spatial arrangement of forest cover has shifted in ways that reduce the extent of interior forest, defined as areas with at least 90% forest cover within a 38-acer neighborhood. The 2.6% net loss of forest cover corresponds to a 6.4% decline in interior forest area, with two-thirds of U.S. counties experiencing a net loss (Riitters et al., 2023). Because gains and losses occur in different locations, this net decline reflects changes across an area equivalent to 27% of the original interior forest. Consequently, measures of net change alone understate the magnitude of landscape transformation, and the spatial pattern of forest change is critical for understanding impacts on biodiversity and ecosystem processes.

2.2. Future Forest Area and Condition

Between 2020 and 2070, total forestland in the conterminous United States is projected to decline by 7.6–15.0 million acres (a 1.9%–3.7% decrease from 2020), with the largest declines occurring under the HH scenario (Table 1). Across all scenarios, most forest loss results from conversion to developed land (Mihiar & Lewis, 2023). Losses are concentrated in the South, where high rates of population and economic growth, combined with predominantly private land ownership, accelerate the conversion of forests to developed uses and expansion of the wildland–urban interface.

These losses are partially offset by forest expansion on former agricultural lands, primarily in the eastern United States. Historically, such transitions have helped maintain a relatively stable forest area. However, the rate of forest expansion is projected to slow, and in some scenarios reverse, as the supply of marginal agricultural land declines and remaining agricultural lands become more profitable for crop production. In addition, some afforestation may occur on native grasslands, creating potential trade-offs with grassland conservation. Together, constraints on the availability of agricultural land and competing conservation priorities are expected to limit future forest expansion.

As a result, projected gains from agricultural land conversion are unlikely to offset ongoing losses to development, resulting in net declines in total forest area over the coming decades. While the magnitude of forest loss is similar across scenarios, the spatial distribution of those losses varies systematically. Forest losses are consistently concentrated in the South, where population and income growth drive conversion to development across all scenarios. In contrast, differences across scenarios are more pronounced in agricultural regions of the Midwest and eastern United States, where the balance between forest expansion and agricultural retention depends on relative profitability under alternative climate and socioeconomic conditions (Mihiar & Lewis, 2023). Northern forests exhibit more modest variation, while land-use change in the western United States is comparatively limited and more strongly influenced by biophysical constraints than by land-use conversion dynamics.

The extent of U.S. forests affected by disturbances such as wildfire, drought, and insect and disease outbreaks is expected to increase in the coming decades, with the largest increases under high-warming scenarios. From 2020 to 2070, the proportion of live tree volume lost to wildfire is projected to increase by 55%–108%, and the area affected by moderate- and high-severity wildfires is expected to at least double (Figure 1). The extent of forest exposure to drought is projected to triple during this period (Costanza, Koch, Reeves, et al., 2023; Costanza,

Table 1
Projected Net Land Use Change From 2020 to 2070 by RPA Scenario and Climate Projection

	LM scenario					HM scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Land use	Million acres (percent)					Million acres (percent)				
Forest	−13.0 (−3.2%)	−11.9 (−2.9%)	−11.9 (−2.9%)	−12.5 (−3.0%)	−12.6 (−3.1%)	−12.5 (−3.0%)	−8.6 (−2.1%)	−11.8 (−2.9%)	−11.9 (−2.9%)	−12.1 (−3.0%)
Developed	51.8 (53.1%)	49.1 (50.4%)	50.7 (51.9%)	51.6 (52.8%)	50.7 (51.9%)	50.2 (51.3%)	43.9 (45.0%)	49.0 (50.2%)	50.1 (51.3%)	48.9 (50.1%)
Crop	−20.6 (−5.8%)	−20.4 (−5.7%)	−23.4 (−6.5%)	−24.4 (−6.8%)	−19.5 (−5.4%)	−19.2 (−5.3%)	−26.9 (−7.5%)	−19.7 (−5.5%)	−23.2 (−6.5%)	−19.3 (−5.4%)
Pasture	−10.6 (−8.9%)	−9.7 (−8.1%)	−7.8 (−6.5%)	−7.6 (−6.4%)	−10.9 (−9.7%)	−11.1 (−9.3%)	−3.7 (−3.1%)	−9.5 (−7.9%)	−8.0 (−6.7%)	−10.3 (−8.6%)
Rangeland	−7.6 (−1.9%)	−7.1 (−1.8%)	−7.6 (−1.9%)	−7.1 (−1.7%)	−7.8 (−1.9%)	−7.5 (−1.8%)	−4.6 (−1.1%)	−8.0 (−2.0%)	−6.9 (−1.7%)	−7.3 (−1.8%)
	HL scenario					HH scenario				
	Climate projection					Climate projection				
	Least warm	Hot	Dry	Wet	Middle	Least warm	Hot	Dry	Wet	Middle
Land use	Million acres (percent)					Million acres (percent)				
Forest	−11.3 (−2.8%)	−7.6 (−1.9%)	−10.7 (−2.6%)	−10.8 (−2.6%)	−11.0 (−2.7%)	−15.0 (−3.7%)	−10.8 (−2.6%)	−14.3 (−3.5%)	−14.5 (−3.5%)	−14.5 (−3.5%)
Developed	47.1 (48.3%)	41.3 (42.4%)	46.1 (47.3%)	47.0 (48.2%)	46.0 (47.2%)	57.0 (58.3%)	49.8 (51.1%)	55.6 (57%)	57.0 (58.3%)	55.3 (56.6%)
Crop	−18.4 (−5.1%)	−26.4 (−7.3%)	−19.0 (−5.3%)	−22.5 (−6.3%)	−18.6 (−5.2%)	−20.8 (−5.8%)	−28.3 (−7.9%)	−21.3 (−5.9%)	−24.9 (−6.9%)	−20.8 (−5.8%)
Pasture	−10.6 (−8.8%)	−3.3 (−2.7%)	−9.0 (−7.5%)	−7.5 (−6.2%)	−9.8 (−8.2%)	−12.3 (−10.3%)	−4.8 (−4.1%)	−10.6 (−8.9%)	−9.2 (−7.7%)	−11.4 (−9.5%)
Rangeland	−6.8 (−1.7%)	−4.0 (−1.0%)	−7.4 (−1.8%)	−6.3 (−1.6%)	−6.6 (−1.6%)	−9.0 (−2.2%)	−5.9 (−1.5%)	−9.5 (−2.3%)	−8.4 (−2.1%)	−8.7 (−2.2%)

Note. LM = lower warming-moderate U.S. growth; HL = high warming-low U.S. growth; HM = high warming-moderate U.S. growth; HH = high warming-high U.S. growth.

Koch, Reeves, 2023). Both the area of forest killed by wildfire and the area exposed to drought are expected to be greatest in the Rocky Mountains, with Pacific Coast forests also likely to face relatively high levels of these disturbances. Tree removals for harvest, including for bioenergy, are projected to rise across the country in all scenarios, with larger increases expected in HH and LM.

Based on empirical models fitted to observed forest data and past climatic and socioeconomic conditions, the projected share of forest area affected by stand-replacing events like high-severity fires remains relatively small at the national level (Coulston, Brooks et al., 2023). Moderate- and high-severity wildfires are projected to burn between 0.07%–0.11% and 0.11%–0.15% of the forest annually across all scenarios by 2070, up from 0.03% to 0.09% in 2020. Tree removals for various purposes, including maintaining forest health and meeting bioenergy demands, are projected to increase nationwide across all future scenarios, with larger increases in the HH and LM scenarios. However, removals stay below the levels seen before the Great Recession (2006–2007) throughout the period in the HL and HM scenarios, and only reach pre-recession levels after 2040 in the HH and LM scenarios (Coulston, Brooks et al., 2023).

By 2070, considering forest growth and succession, remaining forests are expected to become older on average and contain larger tree volumes, despite projected increases in disturbances and management (Coulston, Brooks et al., 2023). By 2070, eastern forests will be about 14 years older than the current average; in the West, the average forest age will increase by roughly 10 years. Furthermore, the proportion of forest in the oldest age classes in both regions (80+ years in the East and 100+ years in the West) will grow. Nationally, the annual net increase

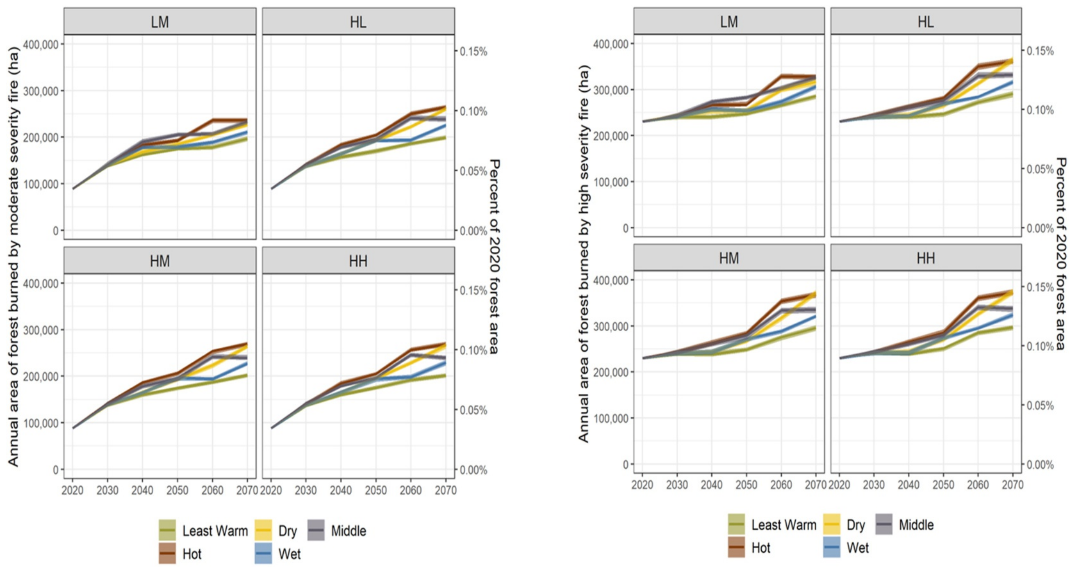

Figure 1. The area of forest burned by (left) moderate and (right) high severity wildfires is expected to at least double by 2070.

in growing stock volume is expected to slow over the projection period across all scenarios, reflecting slower growth rates as trees age. However, annual changes will turn negative after 2050 in the LM and HH scenarios because of higher projected timber harvest removals. Total growing stock volumes for the Rocky Mountain and Pacific regions are projected to increase at the slowest rate of all regions, partly due to the biology and successional dynamics unique to those regions, but also because major forest types are sensitive to changing climate and increased disturbances. Changes in major forest types are expected in those regions, including declines in ponderosa pine and Douglas-fir in the West and decreases in maple/beech/birch in the East.

Across scenarios, the direction of change in disturbance exposure is consistent: all scenario–climate model combinations project increases in wildfire mortality and drought exposure. However, there is meaningful variation in the magnitude and spatial distribution of these changes across climate models. Projections associated with hotter and drier climate futures generally produce larger increases in fire mortality and drought exposure, particularly in the Rocky Mountain and Pacific Coast regions, whereas the least warm climate projections produce smaller increases across all regions. In addition, the relative magnitude of change varies across regions, with western forests experiencing the highest levels of disturbance exposure, while proportional increases are largest in regions such as the South, where baseline disturbance levels are lower.

2.3. Ecosystem Services

This section explores how changes in forests affect biodiversity, water flow, forest products, and recreation. A main contribution of this paper is the integration of RPA Assessment results across resource areas, linking biophysical and socioeconomic processes, both in model inputs and across the broad range of social impacts reported in the RPA Assessment, providing a more complete view of how climate and human factors together influence forest ecosystem services.

2.3.1. Biodiversity

Overlapping species' ranges create a complex pattern of species richness at regional and national levels. These patterns reflect not only climatic stress but also the availability, condition, and spatial configuration of forest habitat, which influence species distributions and the persistence of biodiversity.

The highest species counts occur in the eastern United States, with lower biodiversity in the Pacific and Rocky Mountain regions, for both terrestrial and aquatic biodiversity (Figure 2; Flitcroft et al., 2023). Changes in temperature and precipitation linked to global climate change and habitat loss are already shifting species' ranges

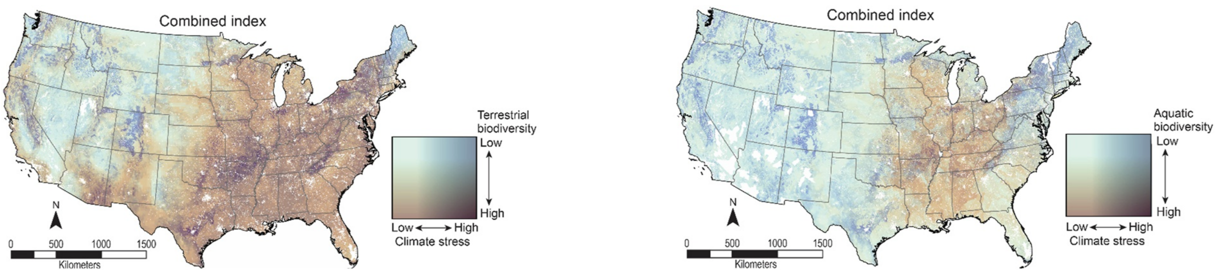

Figure 2. Terrestrial (all taxa) (left) and aquatic (fish, crayfish, and mussels) (right) hot spots with both high biodiversity and a likelihood of high future climate stress. Future climate stress and source information for the biodiversity map described in Flitcroft et al. (2023). Data source for biodiversity: NatureServe, with mapping resolutions of 250 mi^2 for terrestrial results and HUC8 for aquatic results.

and abundances (Howard et al., 2020; Lipton et al., 2018), and these shifts may threaten species as they near their natural climatic limits.

In the RPA biodiversity assessment, terrestrial biodiversity includes species across all relevant taxonomic groups, while aquatic biodiversity encompasses only fish, crayfish, and mussels due to data availability at the time of the 2020 RPA. Patterns of biodiversity are linked to long-term forest disturbance processes related to geological activity and glaciation. However, species at their climatic limits may be further restricted when land use, disturbances, or forest degradation limit refugia.

Climatic stress is expected to be highest in higher-elevation forests, but interactions between climate change and disturbances such as wildfire create a mosaic of high-stress areas throughout the U.S., regardless of elevation (Flitcroft et al., 2023). For terrestrial biota, areas of high biodiversity overlap with climate stress in the Appalachian and Ozark Mountains as well as in the Madrean Sky Islands of Arizona and New Mexico along the U.S.-Mexico border. Additional regions with high terrestrial biodiversity and climate stress are also found in parts of southern Texas and the Northeast (Figure 2, left). Aquatic biodiversity is much more concentrated than terrestrial biodiversity, so overlaying climate stress with aquatic biodiversity shows patterns driven more by biodiversity than by climate. Therefore, climate change-related threats to aquatic biodiversity are greatest in the eastern temperate forests west of the Appalachians (Figure 2, right). Areas with high climate stress but low biodiversity are spread across the western states. Although these regions may have lower overall biodiversity, they support important ecosystems regionally, making it crucial to identify areas of high climate stress for forest management decisions.

2.3.2. Water Yield

Forests provide approximately 39% of the nation's water and play a key role in regulating water yield through their influence on evapotranspiration, infiltration, and runoff (Warziniack et al., 2023). Changes in forest extent and structure, such as those projected in the RPA Assessment, therefore have important implications for future water availability. In turn, water availability influences other forest-dependent ecosystem services, including biodiversity and recreation. The RPA Assessment quantifies the current contribution of forests, including national forests, to water supply and highlights the importance of forests for downstream communities, including municipal drinking water systems and agricultural irrigation. Projections of future water availability are conducted at an all-lands scale, reflecting integrated water supply and demand across landscapes and not isolating forest-specific contributions to future water yield.

Most projections of water yield suggest that the northeastern U.S. and the northern Rocky Mountains will experience wetter conditions by 2070, although these outcomes depend on the extent of temperature increases. Water yield is calculated using the Variable Infiltration Capacity (VIC) model (Liang et al., 1994), which accounts for interactions among the atmosphere, vegetation, and soils that vary with climate conditions. Higher temperatures increase evapotranspiration, which can cause as much variation in water yield as changes in precipitation, depending on the scenario (Figure 3). In many scenarios, the southern U.S. is expected to experience increased evapotranspiration and decreased precipitation, leading to widespread reductions in water yield across the region. There are notable exceptions along the West Coast, where the hot model projects precipitation increases that surpass changes in evapotranspiration, resulting in net gains in water yield.

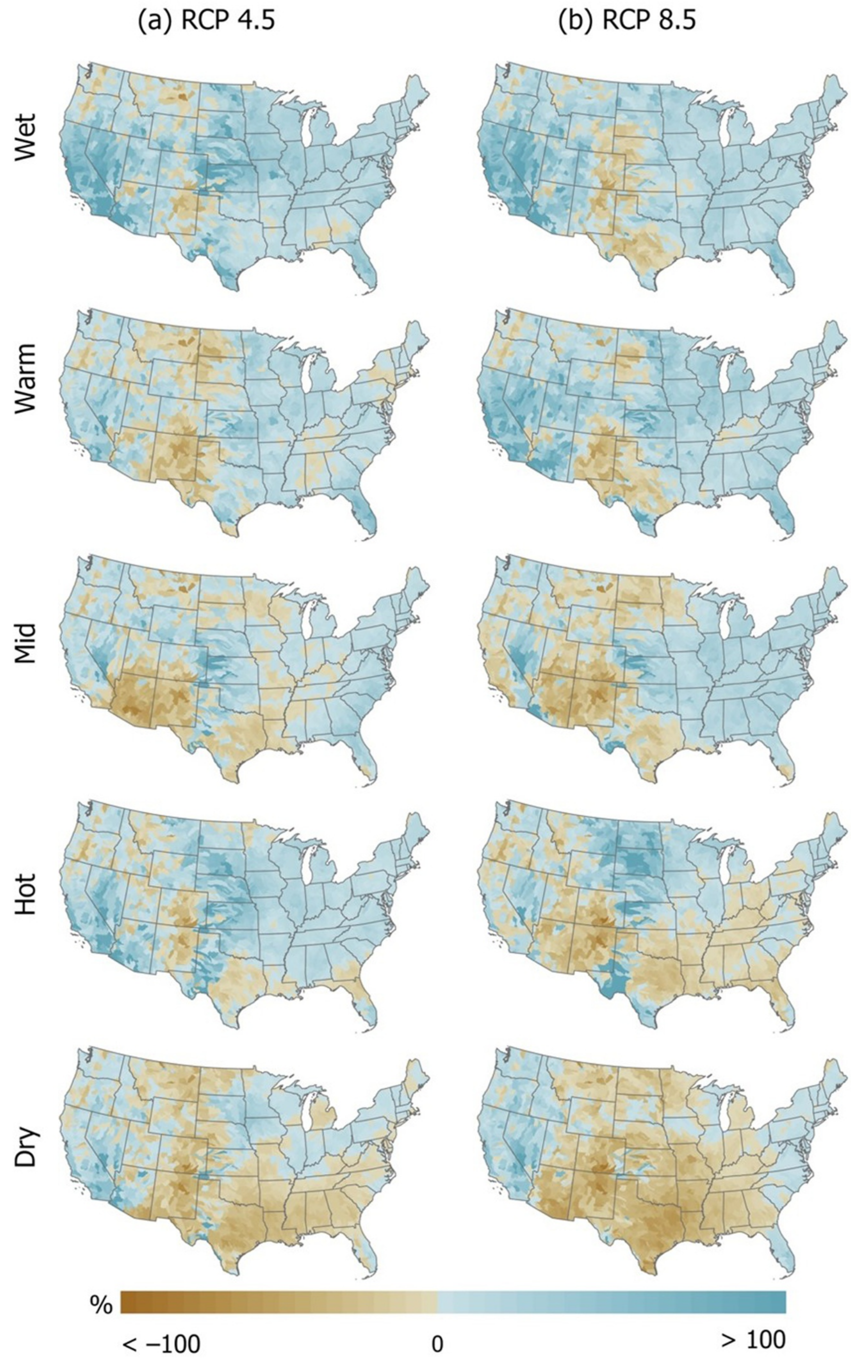

Figure 3. Spatial changes in the 30-year average of annual water yield in response to future climate change from current (1986–2015) to mid-century (2041–2070) for (a) RCP 4.5 and (b) RCP 8.5.

Projections for water yield assume land cover stays the same, based on conditions in the 2015 baseline modeling year. Changes in forest cover, shown in other parts of the RPA Assessment, will affect future hydrology. Unfortunately, these changes have not yet been included in the RPA water yield projections, which is an important limitation of the current modeling framework.

Water use is affected by both climate and socioeconomic factors, with the relative importance of these factors differing across sectors and regions. In large urban areas, total water use (measured as the volume of consumptive use, or withdrawals minus return flows) has decreased in recent decades despite population growth. For example,

10.1029/2025EF007467

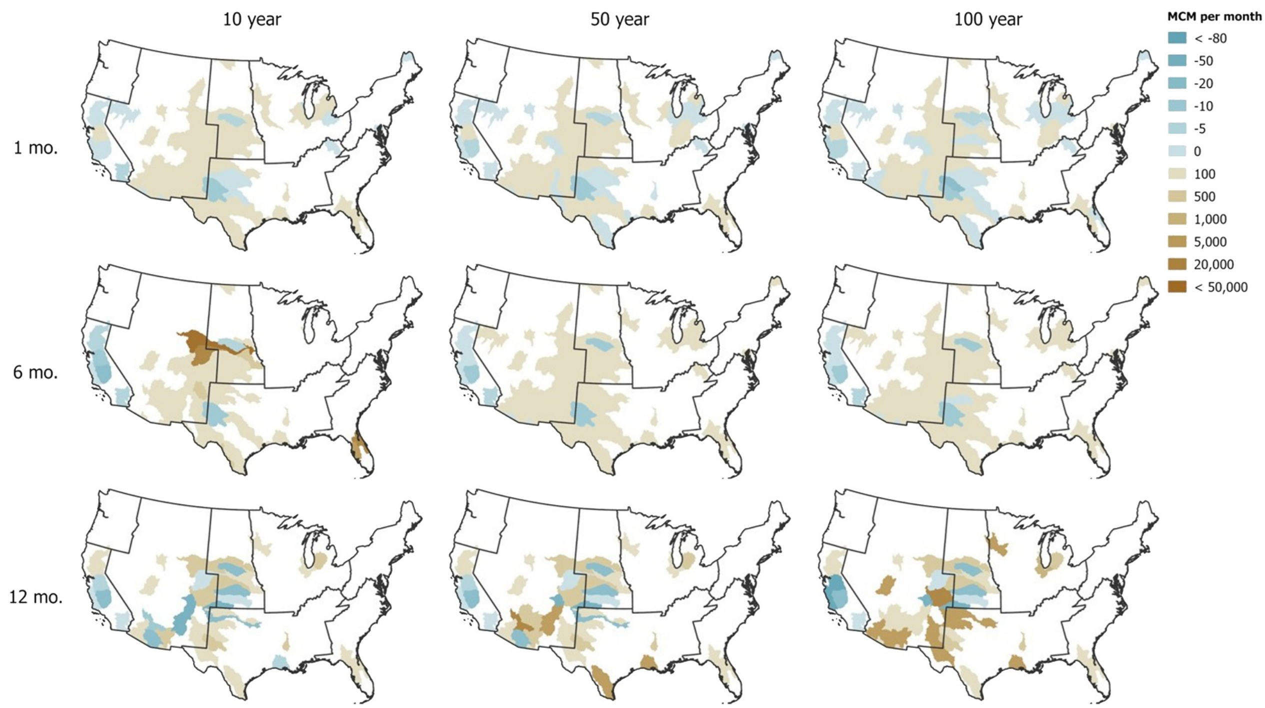

Figure 4. Changes in water shortage events from current (1986–2015) to future (2041–2070) conditions under RCP 8.5. Shortage durations are shown from top to bottom (duration greater than 1 month, greater than 6 months, greater than 12 months). Shortage intensity increases from left to right (shortages that occur on average every 10, 50, or 100 years) (MCM = million cubic meters).

in cities like Las Vegas, Nevada, where water resources have long been stressed, improvements in water efficiency and restrictions on outdoor water use have resulted in declines in per capita water consumption that surpass population growth. Additionally, overall water use is declining in areas where agricultural land is being converted to urban or developed uses, as developed land generally requires less water per unit area than agricultural land. However, in regions where agriculture remains the main water user, rising temperatures will increase evapotranspiration and boost crop water demand. The effects of climate change are expected to be especially significant in agricultural areas projected to become both hotter and drier. Many of these regions, such as the Great Plains and California, already depend heavily on groundwater withdrawals that greatly exceed their natural recharge rates. Consequently, future water shortages are expected to worsen and persist longer, as shown in Figure 4.

2.3.3. Forest Products

Across RPA scenarios, U.S. wood fiber production is projected to rise. The most influential factor affecting harvests is the increase in overall domestic consumer demand for wood, driven by projected income and population growth. Future levels of roundwood production and consumption are likely to vary considerably between now and 2070 across different RPA scenarios. The lowest market activity levels align with steady or declining population changes, while the highest activity levels are associated with significant projected income and population growth (Figure 5).

2.3.4. Recreation

The RPA Assessment examines a wide range of recreational activities to evaluate how climate change and socioeconomic conditions influence human behavior and forest use (White et al., 2023). Many of these activities depend directly on access to forested landscapes and the condition of those forests, linking projected changes in recreation demand to the availability and quality of forest resources.

Results show that future income and population growth are more common drivers of participation in forest-based recreation than climate conditions (Table 2). In most regions, expected increases in income and population will likely lead to more people engaging in outdoor forest recreation. The exceptions are camping, hunting, and off-

10.1029/2025EF007467

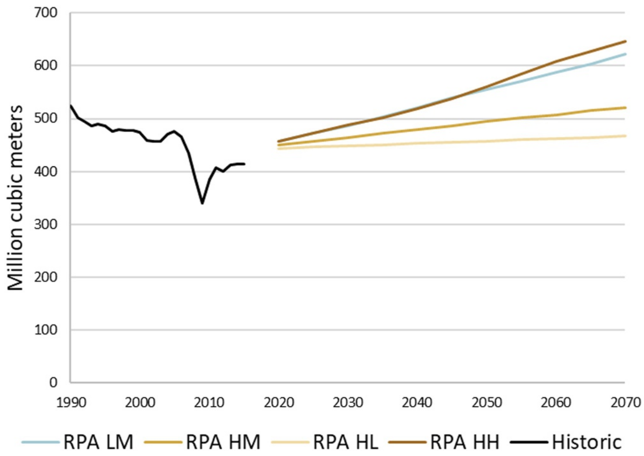

Figure 5. Historical (1990–2015) and projected (2020–2070) U.S. roundwood production by RPA scenario. Roundwood output forecasts vary widely, from near business-as-usual levels to a significant increase, with the position within that range mainly depending on future economic and population growth in the U.S. and worldwide. This also suggests that the United States is expected to continue being a major global producer.

road driving, which are expected to see decreased participation as incomes rise. Significant population growth in the South is expected to cause notable increases in recreation participation across most activities over the next few decades. Across the RPA scenarios, the U.S. population is projected to range from about 316 million under the low-growth pathway (SSP3) to around 594 million under the high-growth pathway (SSP5) by 2070, compared to roughly 334 million in 2020 (Wear & Prestemon, 2019). Under medium- and high-growth scenarios, higher projected populations lead to more people participating in most activities. Developed site visits (such as visiting natural, historic, or prehistoric sites, picnicking, and outdoor family gatherings) are expected to be the most in-demand RPA activities by 2040, with between 105 million and 137 million participants. This is followed by swimming (51–70 million), day hiking (34–45 million), fishing (34–44 million), motorized water activities (31–42 million), and developed site camping (27–34 million). Each of these popular activities is expected to see demand grow by about 30% by 2040. When activity participation rates respond to atmospheric warming, the impact is always negative. The northeastern U.S. states are projected to experience both warming and population decline, leading to substantial decreases in hunting, dispersed snow activities, and camping participation within that region.

3. Discussion

The RPA Assessment provides a unique framework for evaluating how climate and socioeconomic drivers jointly shape future forest conditions across the United States. By integrating multiple socioeconomic pathways with a range of climate projections, the assessment enables direct comparison of the relative impact of these drivers across resource sectors, timeframes, and regions—an insight that isn't possible with single-scenario or climate-only analyses.

Across most ecosystem services, socioeconomic factors, especially population and income growth, are the main drivers of change in the near to mid-term. These forces significantly influence land-use change, recreation demand, and forest product markets. For example, projected decreases in forest area of 7.6–15.0 million acres by 2070 are mainly caused by conversion to developed land, particularly in the South, where rapid population growth and mostly private land ownership increase sensitivity to market pressures. Climate change plays a secondary, supporting role in these outcomes by increasing disturbance rates and reducing forest regeneration capacity, yet it is not the primary cause of forest area loss in most scenarios.

In contrast, climate factors become more influential over longer time horizons and under higher warming scenarios, especially for biophysical processes like water yield, disturbance regimes, and forest productivity. Water yield is a prime example where climate plays a dominant role. Increases in evapotranspiration consistently decrease water availability across regions, largely independent of socioeconomic conditions. Similarly, projections show increases in wildfire, drought, and insect outbreaks across all scenarios, with the extent and distribution of these disturbances heavily affected by climate variability.

Importantly, the influence of climate and socioeconomic factors varies across regions. The South consistently emerges as a hotspot where socioeconomic pressures are dominant, with the greatest projected losses in forest area, the fastest growth in recreation demand, and increasing water stress occurring simultaneously. In contrast, western forests, especially in the Rocky Mountain and Pacific Coast regions, are more strongly affected by climate-driven disturbances, such as wildfire and drought, reflecting both biophysical vulnerability and the larger presence of public land. In agricultural areas of the eastern United States, land-use outcomes depend on the interaction of these forces, where forest expansion or contraction hinges on the relative profitability of agriculture versus forestry under different climate and economic conditions.

In addition to changes in total forest area, the assessment underscores the importance of spatial configuration. Even relatively small net changes in forest extent can lead to substantial losses of interior forest, with important implications for biodiversity and ecosystem function. For species that depend on interior forests, the redistribution and fragmentation of forest cover may be more impactful than overall changes in area. These patterns also

Table 2
The Influence of Socioeconomic Change and Atmospheric Warming on the Share of the Population Engaging in Recreation

Activity or activity grouping	Responsiveness to socioeconomic change or atmospheric warming	Influence of higher levels of socioeconomic growth on per capita participation	Influence of higher levels of atmospheric warming on per capita participation	Combined projected change in per capita participation between 2012 and 2070
Downhill skiing and snowboarding	Socioeconomic change	↑	⇔	↑
Equestrian riding on trails	Socioeconomic change	↑	⇔	↑
Motorized boating	Socioeconomic change	↑	⇔	↑
Developed camping	Socioeconomic change	↓	⇔	↓
Hunting	Socioeconomic change	↓	⇔	↓
Off-road driving	Socioeconomic change	↓	⇔	↓
Day hiking	Both	↑	↓	↑
Canoeing, kayaking, or rafting	Both	↑	↓	↓
Cross-country skiing and snowshoeing	Both	↑	↓	↓
Mountain biking	Both	↑	↓	↑
Snowmobiling	Both	↑	↓	↓
Swimming, snorkeling, and scuba diving	Both	↑	↓	↑
Developed site use—family gatherings, picnicking, etc.	Neither	⇔	⇔	⇔
Viewing nature	Neither	⇔	⇔	⇔
Birding	Neither	⇔	⇔	↓
Undeveloped camping, backpacking, visiting Wilderness	Neither	⇔	⇔	↓
Fishing	Neither	⇔	⇔	↓

Note. Arrows indicate the projected direction change in per capita participation. Bold arrows indicate an unambiguous increase or decrease in projected per capita participation, un-bolded arrows indicate an increase or decrease in per capita participation in most projection cases, and sideways arrows ⇔ indicate no clear outcome or relationship.

highlight that conclusions about biodiversity (and ecosystem services more broadly) depend on the metrics and spatial scale of analysis. For example, well-known biodiversity hotspots, such as California's floristic province, are not strongly reflected in these results because the RPA analysis focuses on faunal species richness at relatively coarse spatial resolution. As a result, the biodiversity patterns identified here differ from those based on plant endemism or fine-scale hotspot analyses.

These patterns have important implications for management and policy. In regions where socioeconomic pressures dominate, such as the South, policies that influence land-use decisions, like conservation incentives or development planning, may be most effective in shaping future outcomes. In contrast, in regions where climate-driven disturbances are more prominent, such as much of the West, management strategies that enhance resilience to fire, drought, and ecological change may be more critical. More broadly, the results suggest that adaptive management strategies will need to account for both evolving economic conditions and increasing climate variability, recognizing that the relative importance of these drivers will shift over time and across regions. Taken together, these results suggest that neither climate nor socioeconomic drivers alone determines the future of U.S. forests; rather, their relative importance varies across resource sectors, regions, and time horizons.

The larger share of land in federal hands in the western U.S. offers an opportunity for broad-scale biodiversity conservation, especially in response to climate stress and wildfires. While working with partners and non-federal groups can help maintain ecological processes and habitat connectivity, there may be opportunities to monitor and support the migration of ecosystems and species into more suitable habitats as climate and landscapes change. However, more work is needed to support assisted migration (Twardek et al., 2023). Still, fragmented migration routes, both in rivers and over land, along with high climate vulnerability in higher-elevation areas on federal lands in the West, could limit their effectiveness as climate refugia. Therefore, management might benefit from more attention to climate vulnerability planning that fosters adaptation as ecosystems change in response to climate effects and shifting disturbance patterns (Ager et al., 2020).

As with any projection-based assessment, these results are subject to uncertainty arising from both future conditions and model structure. Predicting future trajectories of emissions, population growth, and technological change is inherently uncertain, and projections cannot fully anticipate structural shifts associated with major events. For example, when the 2010 RPA Assessment was released, the nation was recovering from a financial crisis and a deep economic recession, which coincided with a historically significant decline in housing construction. Similarly, most of the analysis and writing for the 2020 RPA Assessment occurred during the COVID-19 pandemic. Therefore, projections for recreation did not account for the now-documented shifts in recreation participation observed during the pandemic (e.g., Perren et al., 2023; Shartaj, Suter, and Warziniack, 2022).

More fundamentally, empirically based models reflect the historical periods used for their estimation. Land-use projections in the 2020 RPA Assessment are based on observed patterns from roughly 2000–2015, and therefore reflect the economic conditions, policies, and land-use preferences of that period. Similarly, projections of forest dynamics are informed by observations from approximately 2000–2018, a period with relatively few extreme wildfire years captured at broad spatial scales. As a result, projected disturbance rates, particularly high-severity wildfire, may be conservative if future conditions include more frequent or more severe events than historically observed.

The RPA's scenario-based framework partially addresses these uncertainties by exploring a range of socioeconomic and climate futures across multiple climate models. However, future assessments will benefit from longer observational records, particularly those that capture recent increases in extreme events, as well as continued improvements in data and modeling approaches.

4. Methods

Each resource area relies on independent, empirically based models calibrated to observed data, but all models are driven by a common set of socioeconomic (SSP-based) and climate (RCP/GCM-based) inputs. This shared scenario framework enables consistent comparison across sectors, even though model structure and outputs differ by resource area.

The scenarios used here combine representative concentration pathways (RCPs) and shared socioeconomic pathways (SSPs) to create four core futures: (a) lower atmospheric warming and moderate economic growth (LM scenario), (b) high atmospheric warming with low economic growth (HL), (c) high atmospheric warming with moderate economic growth (HM), and (d) high atmospheric warming with high economic growth (HH) (Figure 6 and Figure A1 in Supporting Information S1). The LM scenario assumes a future with less severe climate change impacts, coupled with moderate economic and population growth in the U.S. and a global focus on sustainability, suggesting a balance between resource use and conservation efforts. The HL scenario predicts more extreme climate change impacts, paired with lower economic and population growth in the U.S. This future entails heightened resource management challenges and the need to implement robust climate adaptation strategies. The HM scenario combines significant climate change impacts with moderate U.S. population growth, reflecting a future where increased resource demands and greater environmental stressors will likely pose significant challenges for land managers and policymakers. The HH scenario is the most intense and projects the most pronounced climate change impacts alongside high economic and population growth. The HH future would lead to the highest demand for natural resources amid extreme environmental pressures, reflecting the most significant challenge and the greatest need for effective management and sustainability practices among the four socioeconomic scenarios we explored.

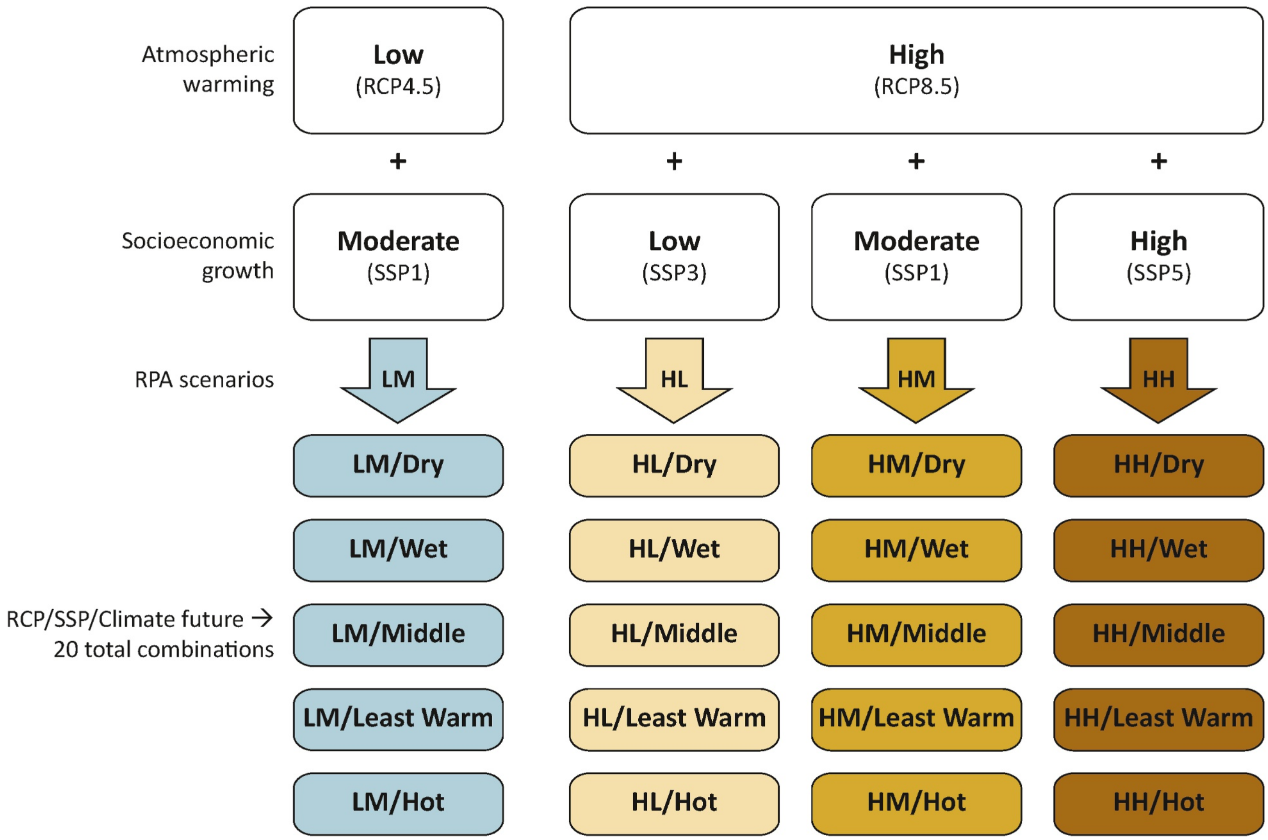

Figure 6. Construction of RPA scenarios combining representative concentration pathways (RCPs), shared socioeconomic pathways (SSPs), and global climate models (GCMs).

Each scenario was paired with downscaled data from five global climate models (GCMs), chosen to represent variation along two dimensions of projected climate change: precipitation and temperature (Abatzoglou, 2013). Joyce and Coulson (2020) show the variation in temperature and precipitation between the future (2041–2070) and reference (1971–2000) periods for the conterminous U.S. and all climate models considered for the RPA Assessment (Figure 7). The wet model (CNRM-CM5), for example, is defined by its "wetness" rather than by combinations of both wet and hot conditions. Similarly, the least warm model (MRI-CGCM3) is relatively cooler than the other models for both RCP 4.5 and RCP 8.5, and is near the ensemble mean precipitation level for RCP 4.5 (but relatively wet for RCP 8.5). The set was also limited to one GCM from each modeling institution for the five projections (least warm, hot, dry, wet, middle) and required the same model to meet those criteria for both RCP 4.5 and RCP 8.5. Although a full GCM ensemble mean can reduce projection uncertainty, individual model variability was prioritized by selecting five GCMs spanning the range of projected temperature and precipitation outcomes. This approach provides a richer characterization of the uncertainty space than a single ensemble mean, allowing resource managers to understand the range of plausible futures rather than a single central tendency (Knutti & Sedláček, 2013).

SSPs were chosen from scenarios defined by the International Institute for Applied Systems Analysis (IIASA; Cuaresma, 2017; Riahi et al., 2017) and do not include climate feedback or policy targets (O'Neill et al., 2014). SSP3 and SSP5 capture a range of economic and demographic changes expected for the U.S. SSP1 and SSP2 were included because they offer interesting variation in resource and sector-specific outcomes that influence natural resources. The approach to choosing SSPs enabled projections of county-level income and population in the U.S. that are consistent with neoclassical growth theory, specifically, income per capita convergence (Wear and Prestemon, 2019a). The theory is based on the economic objectives of capital owners to maximize their returns and of workers to maximize their income. These two objectives encourage owners of capital to invest in low-wage locations and workers to migrate to high-wage locations, which tend to equalize returns to capital and income per capita across space in the long run. Specifically, the method exploited spatiotemporal autocorrelations in both

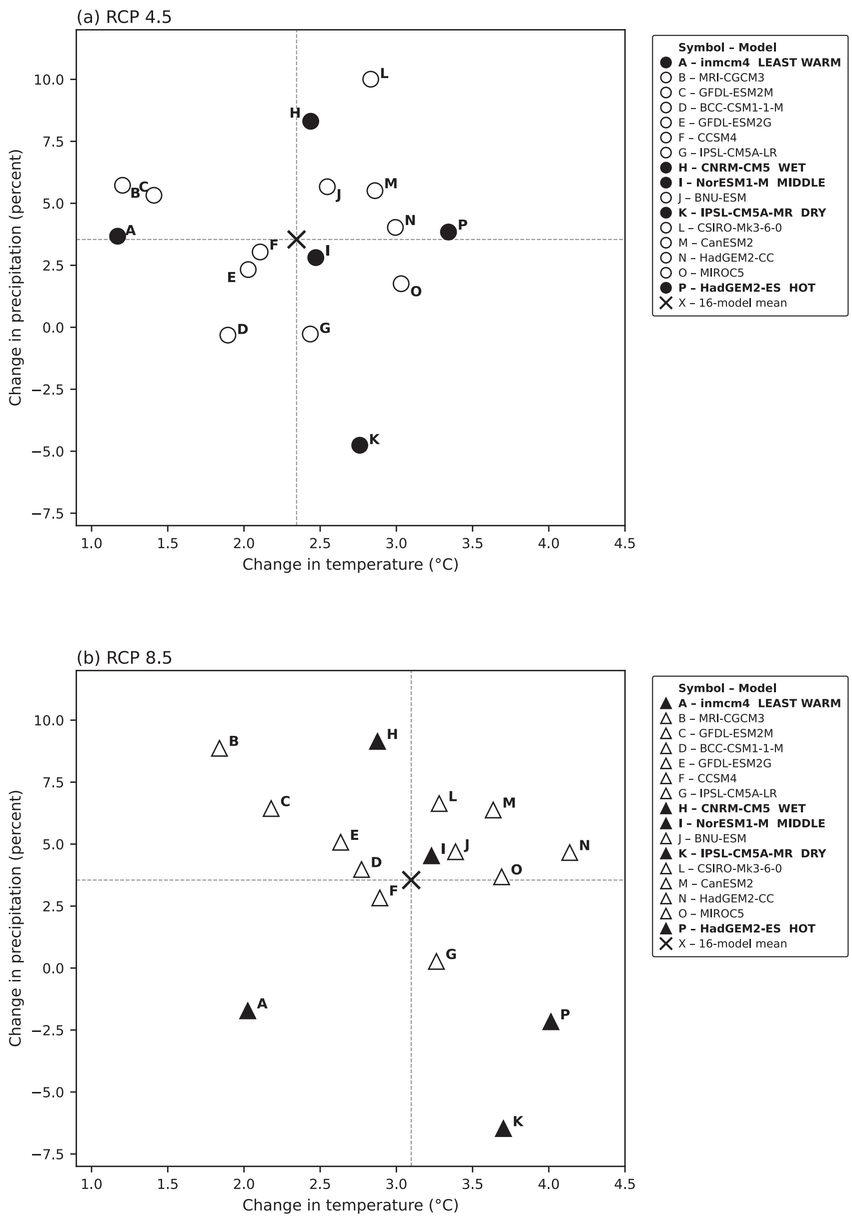

Figure 7. Annual precipitation changes (percent) plotted against mean annual temperature changes (°C) at mid-century (2041–2070) from the historical period (1971–2000) under (a) RCP 4.5 and (b) RCP 8.5 for all 16 models at the conterminous U.S. scale. Individual models are denoted by open circles in the RCP 4.5 scenario and open triangles in the RCP 8.5 scenario. The black "X" represents the mean temperature and precipitation change for the 16 models in each scenario. The core model projections are identified by filled circles or triangles, with notes indicating Least Warm, Hot, Dry, and Middle in the legend (from Joyce and Coulson, 2020).

income and population to quantify the effects of observed agglomeration of people and capital (contagion) and the temporally slow adjustment of both returns and income per capita differentials within the U.S. due to cost-related frictions, parameterized time-invariant unobservable factors influencing levels of both population and income in each county. It recognized inherent uncertainty in the structural form of the convergence models by combining alternative functional forms to generate an ensemble projection. With models trained on historical data, given national projections of income and population change over time, theory-based, internally consistent county-level projections of income and population can be made. RPA Assessment authors applied this approach to generate such projections across five Shared Socioeconomic Pathway scenarios (O'Neill et al., 2014); see Wear and Prestemon (2019b).

10.1029/2025EF007467

Projections of land-use change were generated using an econometric model of plot-level land-use transitions, estimated from the USDA National Resources Inventory (NRI) for the 2000–2012 period (Mihiar & Lewis, 2023). The model estimates transition probabilities among five land use categories (crop, pasture, range, forest, and developed) using a discrete-choice framework. For crop, forest, and developed uses, Ricardian functions link climate to county-level net economic returns, implicitly accounting for climate adaptation in land management by estimating the climate-return relationship from observed landowner behavior. Projected climate conditions from each RPA scenario and GCM combination are used to adjust the estimated net returns, yielding plot-level transition probabilities that are applied within a simulation framework to project land use at two-year intervals from 2020 to 2070. Socioeconomic drivers, including county-level population and income from the downscaled SSP projections (Wear & Prestemon, 2019), serve as additional determinants of land-use change in the model.

Projections of future wildfire area and severity were generated using the RPA Assessment's Forest Dynamics Model (FDM). The FDM is a stochastic modeling system that projected observed (2000–2019) National Forest Inventory (NFI) plot-level variables in 2020 forward to the period 2030–2070 for the conterminous United States at five-year intervals (Coulston, Domke et al., 2023). Projections were based on observed relationships between conditions in plots within the observed NFI and environmental and socioeconomic variables, including climate, timber prices, human population, and income, as a function of plot location (See Coulston, Domke et al. (2023) supplementary material for details on the FDM.) Projections of forest exposure to drought were based on 36-month Standardized Precipitation-Evapotranspiration Index (SPEI; Vicente-Serrano et al., 2010) calculated from MACAv2 climate data for historical observed, historical modeled, and future modeled scenarios. Monthly observed and projected SPEI data were overlaid on NFI plot locations, and inventory data for the forest area represented by each NFI plot were used to calculate the forest area exposed to drought under recent and future scenarios. See Costanza, Koch, Reeves, et al. (2023) and Costanza, Koch, and Reeves (2023) for additional details on the drought exposure methods.

Projections of water yield were created using the Variable Infiltration Capacity (VIC) model version 4.1 (Liang et al., 1994). This model uses topography, soil properties, vegetation, land cover, and meteorological data to estimate runoff and evapotranspiration for roughly 4 km (1/24°) grid cells across the contiguous United States (CONUS). Water yield was then calculated from these simulated outputs of runoff and evapotranspiration. Water use was estimated based on observed trends in water-use efficiency per unit across different economic sectors from 1985 to 2015. For example, historical data from USGS water use circulars show improvements in per capita household water use and per-acer crop irrigation efficiency over recent decades. These trends were linearly extended to 2070 and multiplied by projected population (Wear and Prestemon, 2019b) and irrigated acreage to determine total water use in those sectors at the county level. Water withdrawn for power generation was calculated considering observed efficiency improvements both in water use per kilowatt-hour of energy and in energy requirement per dollar of regional economic output. These per-unit values were then multiplied by projected regional personal income (a measure of economic activity, e.g., from Wear and Prestemon, 2019b). Finally, these projected water yield and use estimates were analyzed to evaluate future water availability and demand within the RPA framework.

The forest products sector in the United States and worldwide was modeled using the Forest Resource Outlook Model (FOROM; Johnston et al., 2021). FOROM is a partial equilibrium model of the global forest sector that estimates forest area, forest inventory, timber production, timber consumption, prices, and international trade. For all countries except the United States, FOROM was calibrated with FAOSTAT data from 2015 (FAO, 2021). For the U.S. forest sector, input data were supplemented with information from the U.S. Forest Service's Timber Product Output (TPO) program and the United States International Trade Commission. The main drivers of future supply and demand for timber and forest products include externally projected trends in gross domestic product, population, technology, trade openness, and bioenergy demand (Bauer et al., 2017), as well as forest productivity in relation to increasing greenhouse gas emissions and a changing climate.

Conflict of Interest

The authors declare no conflicts of interest relevant to this study.

Availability Statement

The RPA Assessment relies on extensive data for analysis. The data and results for the RPA Assessment are available in the Forest Service Research Data Archive, and a full overview of the data and their availability is provided in the RPA Data Quick Reference Guides (USDA, 2023). Climate data and projections are given in Abatzoglou and Brown (2012) and Joyce, Abatzoglou, and Coulson (2018). All data used in this paper were collected with funding from the U.S. Government and can be used without additional permissions or fees.

Acknowledgments
This research was supported [in part] by the U.S. Department of Agriculture, Forest Service. The findings and conclusions in this report are those of the author(s) and should not be interpreted as representing any official USDA or U.S. government policy or determination. The authors wish to thank the broader RPA community and land managers for their continual support and inspiration, and two reviewers whose comments substantially improved this paper.

References

Abatzoglou, J. T. (2013). Development of gridded surface meteorological data for ecological applications and modelling. *International Journal of Climatology*, *33*(1), 121–131. https://doi.org/10.1002/joc.3413

Abatzoglou, J. T., & Brown, T. J. (2012). A comparison of statistical downscaling methods suited for wildfire applications. *International Journal of Climatology*, *32*(5), 772–780. https://doi.org/10.1002/joc.2312

Ager, A. A., Barros, A. M. G., Houtman, R., Seli, R., & Day, M. A. (2020). Modelling the effect of accelerated forest management on long-term wildfire activity. *Ecological Modeling*, *421*(1), 108962. https://doi.org/10.1016/j.ecolmodel.2020.108962

Alcamo, J., Döll, P., Henrichs, T., Kaspar, F., Lehner, B., Rösch, T., & Siebert, S. (2003). Global estimates of water withdrawals and availability under current and future "business-as-usual" conditions. *Hydrological Sciences Journal*, *48*(3), 339–348. https://doi.org/10.1623/hysj.48.3.339.45278

Bauer, N., Calvin, K., Emmerling, J., Fricko, O., Fujimori, S., Hilaire, J., et al. (2017). Shared socio-economic pathways of the energy sector—quantifying the narratives. *Global Environmental Change*, *42*, 316–330. https://doi.org/10.1016/j.gloenvcha.2016.07.006

Bonan, G. B. (2008). Forests and climate change: Forcings, feedbacks, and the climate benefits of forests. *Science*, *320*(5882), 1444–1449. https://doi.org/10.1126/science.1155121

Costanza, J. K., Koch, F. H., Reeves, M., Potter, K. M., Schleeweis, K., Riitters, K., et al. (2023). Disturbances to forests and rangelands. In *2023. Future of America's Forest and rangelands: Forest Service 2020 Resources Planning Act assessment. Gen. Tech. Rep. WO-102* (Vol. Chapter 5, pp. 5-1–5-55). U.S. Department of Agriculture, Forest Service. https://doi.org/10.2737/WO-GTR-102-Chap5

Costanza, J. K., Koch, F. H., & Reeves, M. C. (2023). Future exposure of forest ecosystems to multi-year drought in the United States. *Ecosphere*, *14*(5), e4525. https://doi.org/10.1002/ecs2.4525

Coulston, J. W., Brooks, E. B., Butler Brett, J., Costanza, J. K., Walker, D. M., & Domke, G. M. (2023). Forest resources. In *Future of America's forest and rangelands: Forest Service 2020 Resources Planning Act Assessment (Gen. Tech. Rep. WO102. Chapter 6, 2023)* (pp. 1–6).

Coulston, J. W., Domke, G. M., Walker, D. M., Brooks, E. B., & O'Dea, C. B. (2023). Near-term investments in forest management support long-term carbon sequestration capacity in forests of the United States. *PNAS Nexus*, *2*(11), pgad345. https://doi.org/10.1093/pnasnexus/pgad345

Crimmins, A. R., Avery, C. W., Easterling, D. R., Kunkel, K. E., Stewart, B. C., & Maycock, T. K. (2023). Fifth national climate assessment. https://doi.org/10.7930/NCA5.2023

Cuaresma, J. C. (2017). Income projections for climate change research: A framework based on human capital dynamics. *Global Environmental Change*, *42*, 226–236. https://doi.org/10.1016/j.gloenvcha.2015.02.012

Cutter, S. L., Emrich, C. T., Webb, J. J., & Morath, D. (2009). Social vulnerability to climate variability hazards: A review of the literature. *Final Report to Oxfam America*, *5*, 1–44.

Domke, G. M., Fettig, C. J., Marsh, A. S., Baumflek, M., Gould, W. A., Halofsky, J. E., et al. (2023). Ch. 7. Forests. In *Fifth national climate assessment*.

FAO. (2021). *Forestry production and trade*. Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/faostat/en/#data/FO

Flitcroft, R. L., Bury, G. W., Joyce, L. A., Kay, S. L., Knowles, M. S., & Nelson, M. D. (2023). Biodiversity: Wildlife and aquatic biota. In *Future of America's forest and rangelands* (pp. 231–256). U.S. Department of Agriculture, Forest Service. https://doi.org/10.2737/WO-GTR-102-Chap10

Foley, J. A., DeFries, R., Asner, G. P., Barford, C., Bonan, G., Carpenter, S. R., et al. (2005). Global consequences of land use. *Science*, *309*(5734), 570–574. https://doi.org/10.1126/science.1111772

Howard, C., Flather, C. H., & Stephens, P. A. (2020). A global assessment of the drivers of threatened terrestrial species richness. *Nature Communications*, *11*(1), 993. https://doi.org/10.1038/s41467-020-14771-6

Johnston, C. M. T., Guo, J., & Prestemon, J. P. (2021). *The Forest Resource Outlook Model (FOROM): A technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. SRS-254* (p. 19). U.S. Department of Agriculture, Forest Service, Southern Research Station. https://doi.org/10.2737/SRS-GTR-254

Joyce, L. A., Abatzoglou, J. T., & Coulson, D. P. (2018). Climate data for RPA 2020 assessment: MACAv2 (METDATA) historical modeled (1950-2005) and future (2006-2099) projections for the conterminous United States at the 1/24 degree grid scale [Dataset]. *Forest Service Research Data Archive*. https://doi.org/10.2737/RDS-2018-0014

Joyce, L. A., & Coulson, D. (2020). *Climate scenarios and projections: A technical document supporting the USDA Forest Service 2020 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-413* (p. 85). US Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-413

Knutti, R., & Sedláček, J. (2013). Robustness and uncertainties in the new CMIP5 climate model projections. *Nature Climate Change*, *3*(4), 369–373. https://doi.org/10.1038/nclimate1716

Liang, X., Lettenmaier, D. P., Wood, E. F., & Burges, S. J. (1994). A simple hydrologically based model of land surface water and energy fluxes for general circulation models. *Journal of Geophysical Research*, *99*(D7), 14415–14428. https://doi.org/10.1029/94JD00483

Lipton, D. M. A., Rubenstein, S. R., Weiskopf, S., Carter, S., Peterson, J., Crozier, L., et al. (2018). Ecosystems, ecosystem services, and biodiversity. In D. Reidmiller, C. Avery, D. Easterling, et al. (Eds.), *Impacts, risks, and adaptation in the United States: Fourth national climate assessment* (Vol. II, pp. 269–321). United States Global Change Research Program.

Mihiar, C. M., & Lewis, D. J. (2023). An empirical analysis of US land-use change under multiple climate change scenarios. *Journal of the Agricultural and Applied Economics Association*, *2*(3), 597–611. https://doi.org/10.1002/jaa2.82

Newbold, T., Hudson, L. N., Hill, S. L. L., Contu, S., Lysenko, I., Senior, R. A., et al. (2015). Global effects of land use on local terrestrial biodiversity. *Nature*, *520*(7545), 45–50. https://doi.org/10.1038/nature14324

O'Neill, B., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., et al. (2014). A new scenario framework for climate change research: The concept of shared socioeconomic pathways. *Climate Change*, *122*(3), 387–400. https://doi.org/10.1007/s10584-013-0905-2

Oswalt, S. N., Smith, W. B., Miles, P. D., & Pugh, S. A., & coords. (2019). *Forest resources of the United States, 2017: A technical document supporting the Forest Service 2020 RPA Assessment. Gen. Tech. Rep. WO-97* (p. 223). U.S. Department of Agriculture, Forest Service, Washington Office. https://doi.org/10.2737/WO-GTR-97

Perren, C., Boley, B., Green, G. T., & White, E. M. (2023). Fad or renaissance? Motivational and demographic characteristics of USDA Forest Service recreationists during and after the pandemic. *Journal of Outdoor Recreation and Tourism*, *44*(1), 100700. https://doi.org/10.1016/j.jort.2023.100700

Radeloff, V. C., Helmers, D. P., Kramer, H. A., Mockrin, M. H., Alexandre, P. M., Bar-Massada, A., et al. (2018). Rapid growth of the U.S. wildland-urban interface raises wildfire risk. *Proceedings of the National Academy of Sciences*, *115*(13), 3314–3319. https://doi.org/10.1073/pnas.1718850115

Riahi, K., van Vuuren, D. P., Kriegler, E., Edmonds, J., O'Neill, B. C., Fujimori, S., et al. (2017). The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change*, *42*, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009

Riitters, K., Coulston, J. W., Mihiar, C., Brooks, E. B., Greenfield, E. J., Nelson, M. D., et al. (2023). Land resources. In: *2023. Future of America's Forest and Rangelands: Forest Service 2020 Resources Planning Act Assessment Gen. Tech. Rep. WO-102* (Vol. Chapter 4, pp. 4-1–4-37). U.S. Department of Agriculture, Forest Service. https://doi.org/10.2737/WO-GTR-102-Chap4

Sanchez, L., Warziniack, T., & Knowles, M. (2023). The inequitable exposure of socially vulnerable groups to water shortages across the United States. *Environmental Research Letters*, *18*(4), 044022. https://doi.org/10.1088/1748-9326/acb06d

Shartaj, M., Suter, J. F., & Warziniack, T. (2022). Summer crowds: An analysis of USFS campground reservations during the COVID-19 pandemic. *PLoS One*, *17*(1), e0261833. https://doi.org/10.1371/journal.pone.0261833

Twardek, W. M., Taylor, J. J., Rytwinski, T., Aitken, S. N., MacDonald, A. L., Van Bogaert, R., & Cooke, S. J. (2023). The application of assisted migration as a climate change adaptation tactic: An evidence map and synthesis. *Biological Conservation*, *280*, 109932. https://doi.org/10.1016/j.biocon.2023.109932

United States Global Change Research Program [USGCRP]. (2018). In D. R. Reidmiller, C. W. Avery, D. R. Easterling, K. E. Kunkel, K. L. M. Lewis, et al. (Eds.), *Impacts, risks, and adaptation in the United States: Fourth national climate assessment, Volume II*. 1515. U.S. Global Change Research Program. https://doi.org/10.7930/NCA4.2018

U.S. Department of Agriculture (USDA). (2015). *Summary report: 2012 National Resources Inventory*. U.S. Department of Agriculture, Forest Service, Natural Resources Conservation Service. Iowa State University, Center for Survey Statistics and Methodology. Retrieved from http://www.nrcs.usda.gov/technical/nri/12summary

U.S. Department of Agriculture (USDA). (2023). RPA data quick reference guides [Dataset]. Retrieved from https://research.fs.usda.gov/inventory/rpaa/datause

Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The standardized precipitation evapotranspiration index. *Journal of Climate*, *23*(7), 1696–1718. https://doi.org/10.1175/2009JCLI2909.1

Warziniack, T., Allor, L., Bunn, D., & McHale, M. (2024). Forests as social–ecological systems. In *Future forests* (pp. 265–278). Elsevier.

Warziniack, T., Arabi, M., Froemke, P., Ghosh, R., Heidari, H., Rasmussen, S., & Swartzentruber, R. (2023). Water resources. In *2023. Future of America's Forest and rangelands: Forest Service 2020 Resources Planning Act Assessment. Gen. Tech. Rep. WO-102* (pp. 1–9). US Department of Agriculture, Forest Service.

Wear, D. N., & Prestemon, J. P. (2019). Spatiotemporal downscaling of global population and income scenarios for the United States. *PLoS One*, *14*(7), e0219242. https://doi.org/10.1371/journal.pone.0219242

Wear, D. N., & Prestemon, J. P. (2019a). Spatiotemporal downscaling of global population and income scenarios for the United States. *PLoS One*, *14*(7), e0219242. https://doi.org/10.1371/journal.pone.0219242

Wear, D. N., & Prestemon, J. P. (2019b). *Socioeconomic data for the Forest Service 2020 RPA Assessment*. Forest Service Research Data Archive. https://doi.org/10.2737/RDS-2019-0041

Weiskopf, S. R., Rubenstein, M. A., Crozier, L. G., Gaichas, S., Griffis, R., Halofsky, J. E., et al. (2020). Climate change effects on biodiversity, ecosystems, ecosystem services, and natural resource management in the United States. *Science of the Total Environment*, *733*, 137782. https://doi.org/10.1016/j.scitotenv.2020.137782

White, E. M., Askey, A. E., & Bowker, J. M. (2023). Outdoor recreation and wilderness. In *2023. Future of America's Forest and Rangelands: Forest Service 2020 Resources Planning Act Assessment. Gen. Tech. Rep. WO-102* (Vol. Chapter 11, pp. 11-1–11-37). U.S. Department of Agriculture, Forest Service. https://doi.org/10.2737/WO-GTR-102-Chap11

References From the Supporting Information

Langner, L. L., Joyce, L. A., Wear, D. N., Prestemon, J. P., Coulson, D., & O'Dea, C. B. (2020). *Future scenarios: A technical document supporting the USDA Forest Service 2020 RPA Assessment. Gen. Tech. Rep. RMRS-GTR-412* (p. 34). U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-412