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Strategic Forest Reserves can protect biodiversity in the western United States and mitigate climate change

Beverly E. Law[1✉], Logan T. Berner[2], Polly C. Buotte[3], David J. Mildrexler[4] & William J. Ripple[1]

Forest preservation is crucial for protecting biodiversity and mitigating climate change. Here we assess current forest preservation in the western United States using spatial data and find that beyond the 18.9% (17.5 Mha) currently protected, an additional 11.1% (10.3 Mha) is needed to achieve 30% preservation by 2030 (30 × 30). To help meet this regional preservation target, we developed a framework that prioritizes forestlands for preservation using spatial metrics of biodiversity and/or carbon within each ecoregion. We show that meeting this preservation target would lead to greater protection of animal and tree species habitat, current carbon stocks, future carbon accumulation, and forests that are important for surface drinking water. The highest priority forestlands are primarily owned by the federal government, though substantial areas are also owned by private entities and state and tribal governments. Establishing Strategic Forest Reserves would help protect biodiversity and carbon for climate adaptation and mitigation.

[1] Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR, USA. [2] EcoSpatial Services L.L.C., Flagstaff, AZ, USA. [3] Energy and Resources Group, University of California Berkeley, Berkeley, CA, USA. [4] Eastern Oregon Legacy Lands, Joseph, OR, USA. ✉email: lawb@oregonstate.edu

We are in the midst of climate and biodiversity emergencies[1], and pledges have been made by the world's governments to address both. Studies suggest that countries must ramp up climate pledges by 80% to avoid the most catastrophic effects of climate change[2]. International, national, and state biodiversity targets have been established to include protection of 30% of the land by 2030 (30 × 30), and 50% by 2050 (50 × 50)[3,4], a timeframe over which accelerated abrupt ecological disruption is expected[5]. In addition to the targets, the United States (US) stated it's understanding of the role of natural climate solutions in climate mitigation and resilience in its Nationally Determined Contributions in line with Article 4 of the Paris Agreement[6]. Nevertheless, only 6.1% of forestland in the conterminous US is protected at the highest level (Supplementary Table 1), with 0.2% in strict nature reserves to protect biodiversity, 4.8% in Wilderness areas, and 1.1% in National Parks[7]. How do we achieve our preservation targets given the pressing need to increase carbon removals from the atmosphere, make substantial reductions in carbon emissions, protect biodiversity, and slow the accelerating species losses?

The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Intergovernmental Panel on Climate Change (IPCC) jointly recognized the intertwined nature of climate and biodiversity[8]. Their landmark report highlights the synergies and trade-offs between protection of biodiversity and climate change adaptation and mitigation, and recommend measures that can be jointly taken[8]. Global studies have identified terrestrial areas that, if preserved, would stem biodiversity loss, prevent carbon emissions from land conversion, and enhance natural carbon removal from the atmosphere[9–11]. Although global studies provide estimates of the role of natural climate solutions to store carbon[12] or benefit biodiversity and carbon storage[10], regional analyses with finer resolution information are needed at a scale appropriate to inform decision-making. Our analysis here is among the first to apply recommendations of the IPBES-IPCC report to forests in a specific geographic region.

Emissions from land cover and land use change now exceed half of removals from the atmosphere by all terrestrial ecosystems[13]. Much attention has been on reducing deforestation and degradation in tropical forests because of their large extent[14], high biodiversity[15], and carbon density[16], and because tropical deforestation and degradation are the second largest source of anthropogenic emissions after fossil fuel emissions[13]. Deforestation and degradation result in habitat loss that is a major cause of species extinctions, and contribute to warming that amplifies risk of species extinction[17]. Little attention has been given to the nexus of high carbon density and biodiversity forests in the temperate region, and their importance to climate mitigation and adaptation.

Across forests of the western US an earlier study found that medium to high carbon density forests (carbon per unit ground area) with low vulnerability to mortality from fire or drought by 2099 also had high amounts of critical habitat for threatened and endangered species[18]. The study focused on high carbon priority areas for protection that had low vulnerability to mortality, but did not prioritize areas for biodiversity, identify preservation opportunities within each ecoregion, or distinguish land ownerships as a factor for decision-making.

Here, we develop and apply a regional framework to identify forest areas in the western US (Fig. 1) for permanent protections that if preserved, would stem further biodiversity loss, prevent emissions from forest conversion, and safeguard natural carbon stocks and accumulation. This regional framework is unique in that it evaluates the current extent of protected areas and then explicitly determines ways to reach specific forest preservation targets based on three preservation priority scenarios (carbon and/or biodiversity; Fig. 2). We focus on the following questions:

(1) How much forestland is currently protected in each western state and how much additional forestland would need to be protected to reach the 30 and 50% targets?
(2) Which forestlands are the highest priority for preservation to meet these targets if prioritized based on forest carbon and/or biodiversity scenarios?
(3) Who owns the forestlands that have the highest preservation priority under each scenario?
(4) If these targets were reached, then for each scenario how much forest carbon and species habitat would occur in protected areas compared with present?

The spatial extent of the analysis is 92.46 Mha of forest land in the western US. We first determined current forest preservation status and how much additional forest would be needed to meet the 30 × 30 and 50 × 50 targets in the western US. Specifically, we identified the regional extent of forests at 1 km resolution using a geospatial dataset produced by the US Forest Service (USFS) Forest Inventory and Analysis program (FIA)[19] and determined current preservation status using the Protected Areas Database of the United States (PAD-US version 2.1) from the US Geological Survey (USGS) Gap Analysis Project (GAP)[20]. To identify forests with the highest preservation priority, we developed a forest preservation priority ranking (forest PPR) system using geospatial data related to forest biodiversity, carbon, and future vulnerability to drought or wildfire (Fig. 2). To ensure protection for the many facets of regional biodiversity and promote regional connectivity, we computed the forest PPR components for each grid cell relative to other grid cells in the same ecoregion within each state. Forest biodiversity was characterized based on terrestrial vertebrate (hereafter *animal*) and tree species richness derived from species habitat distribution models produced by the USGS GAP[21] and USFS FIA[22], respectively. Current forest ecosystem carbon

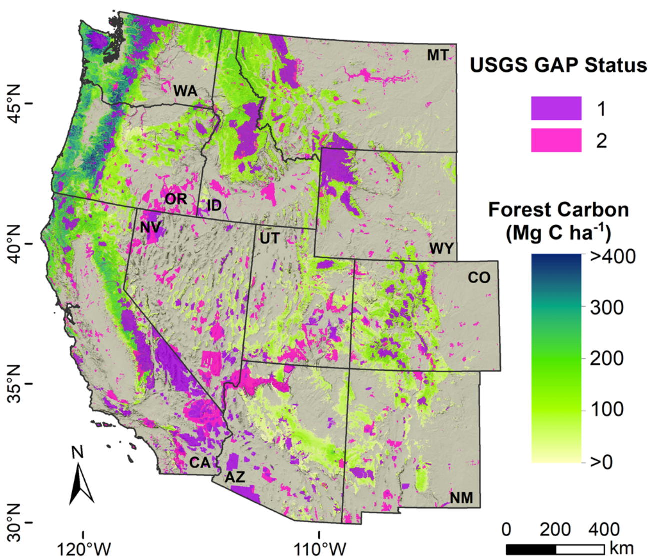

Fig. 1 Current protected lands and forest ecosystem carbon stocks (Mg C ha^{-1}) across the western US. Protected lands shown here are those with GAP Status 1 or 2 from the Protected Areas Database of the United States (PAD-US v. 2.1)[20]. These statuses reflect areas with permanent protection from anthropogenic conversion of natural land cover. The forest carbon stocks were spatially imputed from inventory measurement by the USFS FIA[23]. The protected lands shown here include forestlands and non-forestlands.

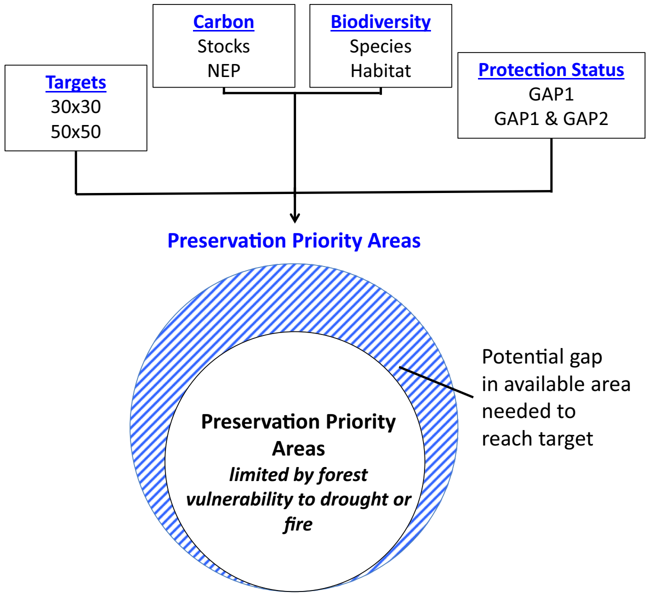

Fig. 2 Analysis framework for prioritizing areas for forest carbon and/or biodiversity preservation across the western US. Regional framework evaluates the current extent of protected areas and then explicitly determines ways to reach specific forest preservation targets based on three preservation priority scenarios (carbon, biodiversity, carbon, and biodiversity).

stocks (2000 to 2009) were quantified using a dataset produced by the USFS FIA[23], while potential forest carbon accumulation from 2020 to 2050 was quantified using cumulative net ecosystem production simulated with a region- and species-specific parameterized version of the Community Land Model version 4.5 (CLM4.5)[24]. These previous simulations used climatic changes predicted by two global climate models forced by representative concentration pathway 8.5 emissions[18]. Future forest vulnerability to drought or wildfire was also derived from these simulations[25] and allowed us to compute forest PPRs both including and excluding forests with high vulnerabilities. High vulnerability to future mortality indicates future increases in tree mortality rates which reduces overall carbon storage capacity and has the potential to trigger transitions from forest to non-forest, however explicit vegetation transitions were not simulated. After identifying forests with the highest preservation priority for meeting preservation targets under each prioritization scenario (i.e., biodiversity and/or carbon), we then assessed who owns these forests using ownership data from PAD-US. We also evaluated current and potential protection of not only animal and tree species habitat, but also current carbon stocks, near future carbon accumulation, and forests important for surface drinking water.

Our analysis reveals that to achieve 30% permanent protection of forestland in the region by 2030, an additional 10.3 Mha (11.1%) would need to be protected at the highest levels (herein referred to as GAP 1 and GAP 2). We find that meeting preservation targets would help protect regional forest carbon, biodiversity, and surface drinking water. Establishing Strategic Forest Reserves on public lands would provide climate mitigation, biodiversity protection, and water security.

Results

Current extent and additional protected area needed to meet targets. Protected areas are defined by the USGS GAP as lands dedicated to and actively managed for the preservation of biological diversity, recreation, and cultural uses. GAP status 1 and GAP status 2 are the highest levels of protection with mandated management plans to maintain a natural state (Supplementary Table 1). In GAP 1 areas, ecological disturbances are allowed to proceed, while GAP 2 areas may receive uses or management practices that degrade the quality of existing natural communities, including suppression of natural disturbance like wildfire. Protecting 30% by 2030 using both GAP 1 and 2 means the targeted lands will have met these criteria for permanent protection and have mandatory management plans that do not allow extractive uses (e.g., logging, livestock grazing, mining).

Our analysis showed that about 7.6% (23.2 Mha) of the land area in the region is protected at the highest level (GAP 1), of which about half (55%, 13 Mha) is forest. About 14.0% of regional forest area is GAP1 and thus to achieve 30% protection by 2030, an additional 16.0% (14.8 Mha) of forest area needs to be protected (Supplementary Table 2). If the analysis is relaxed to include both GAP 1 and GAP 2, then 18.9% forest area is currently protected and an additional 11.1% (10.3 Mha) of forest area would need to be protected by 2030 (Table 1).

Permanently protected land area (GAP 1 and 2) covers an average of 13.2% of each state, but ranges from 6.2% in New Mexico to 23.9% in California (Fig. 1; Table 1). Similarly, permanently protected areas cover an average of 20.2% of forest area in each state, but range from 10.1% in Oregon to 41.9% in Wyoming (~1 to 3 Mha per state). To protect 30% of forest area by 2030 and 50% by 2050, each state would need to increase protection by 0–19.9% and 8.1–36.8%, respectively, while region-wide protection would need to increase by 11.1% and 31.1% to achieve these targets (Table 1).

The area required to protect habitat and ecosystems from being imperiled is estimated to be about half of a typical region or ecoregion[26]. Of the 28 ecoregions in the western US that are at least 1% forested, 21% ($n = 6$) have at least 30% of their forest area permanently protected as GAP 1 or 2, while only 7% ($n = 2$) have at least half of their forest area protected at these levels (Supplementary Table 3).

Highest priority areas for preservation of carbon and biodiversity. Forest PPRs were derived from carbon and biodiversity priority ranks at 1 km spatial resolution computed when both including and excluding forestland with high future vulnerability as simulated with CLM4.5, and summarized by ecoregion and state. The areas with the highest forest PPRs are primarily in the mountain ranges (Fig. 3a), particularly in the Pacific Northwest. Forests with high carbon priority have high biodiversity priority when highly vulnerable forests are excluded (Spearman's correlation within ecoregions median $r = 0.52$; Figs. 3, 4). However, there are important areas of high biodiversity that do not have the highest carbon rankings. Prominent examples include the Klamath Mountains in southern Oregon and northern California, the east slope of the Cascades in Washington, some of the Sky Island ranges in Nevada and Utah, Arizona, and the Colorado front range (Fig. 3). The Sky Islands are isolated mountain ranges above the desert or grasslands that connect the subtropical Sierra Madre of Mexico with the temperate Rocky Mountains, creating unique biodiversity.

Future increases in tree mortality rates, represented by high future vulnerability to drought and/or fire[25], could destabilize carbon[27] and biodiversity[28,29]. Much of the southwest US, and portions of the Sierra Mountains and northwestern Wyoming are highly vulnerable to future drought and/or fire, (Fig. 3d, Table 2). Forests in the Pacific Northwest, which currently support high carbon and biodiversity, are less vulnerable to future mortality (Fig. 3). Areas that are highly vulnerable to future mortality, though concentrated in the water-limited forests of the southwest

Table 1 Current extent of forest, protected lands, and additions needed to meet preservation targets for each state and the broader western US.

State	Land	Protected lands		Forest		Protected forest		Additions needed to meet preservation targets							
								All lands				Forest			
								30% target		50% target		30% target		50% target	
	Mha	Mha	%	Mha	%	Mha	%	Mha	%	Mha	%	Mha	%	Mha	%
AZ	29.53	3.81	12.9	7.67	26.0	1.01	13.2	5.0	17.1	11.0	37.1	1.3	16.8	2.8	36.8
CA	40.92	9.76	23.9	11.97	29.3	2.83	23.6	2.5	6.1	10.7	26.1	0.8	6.4	3.2	26.4
CO	26.96	2.61	9.7	9.50	35.2	1.56	16.4	5.5	20.3	10.9	40.3	1.3	13.6	3.2	33.6
ID	21.64	3.16	14.6	9.53	44.0	1.91	20.0	3.3	15.4	7.7	35.4	1.0	10.0	2.9	30.0
MT	38.07	3.41	9.0	9.57	25.1	2.15	22.5	8.0	21.0	15.6	41.0	0.7	7.5	2.6	27.5
NM	31.47	1.95	6.2	6.74	21.4	0.87	12.9	7.5	23.8	13.8	43.8	1.2	17.1	2.5	37.1
NV	28.63	4.40	15.4	3.60	12.6	0.97	26.9	4.2	14.6	9.9	34.6	0.1	3.1	0.8	23.1
OR	25.12	2.93	11.7	12.68	50.5	1.28	10.1	4.6	18.3	9.6	38.3	2.5	19.9	5.1	39.9
UT	21.98	2.81	12.8	6.93	31.5	1.1	15.9	3.8	17.2	8.2	37.2	1.0	14.1	2.4	34.1
WA	17.43	2.62	15.0	10.00	57.4	2.01	20.1	2.6	15.0	6.1	35.0	1.0	9.9	3.0	29.9
WY	25.32	3.62	14.3	4.27	16.9	1.79	41.9	4.0	15.7	9.0	35.7	−0.5	−11.9	0.3	8.1
Region	307.07	41.08	13.4	92.46	30.1	17.48	18.9	51	16.6	112.4	36.6	10.3	11.1	28.8	31.1

Land includes inland waters and was considered currently protected with a GAP status of 1 or 2. States include Arizona (AZ), California (CA), Colorado (CO), Idaho (ID), Montana (MT), New Mexico (NM), Nevada (NV), Oregon (OR), Utah (UT), Washington (WA), and Wyoming (WY).

US, contain a range of current carbon and biodiversity rankings (Fig. 3). Notable high vulnerability areas with high biodiversity occur in the Southern Rockies, the Sierra Nevada, and Greater Yellowstone Ecosystem (Fig. 3). General spatial patterns of 30 and 50% preservation priority appear to be similar between inclusion and exclusion of high vulnerability areas, though fine scale differences are evident for several states in the Southwest (Fig. 4).

Land ownership under high preservation priority scenarios. Regional forestlands with the highest preservation priority are primarily owned by the federal government followed by private entities, tribal governments, and state governments, though the relative proportions vary by target and priority (Fig. 5), as well as among individual states (Supplementary Figs. 1 and 2). The federal government owns more than half (61–62%) of high preservation priority forestland in the region, while states own 4 to 5% (Fig. 5), comprising the lands most readily available for permanent protections under GAP 1 and 2. Private entities own about a quarter of these forestlands, with the bulk of those lands in industrial management and a substantial percentage managed for multiple values. Inventoried Roadless Areas (IRAs) comprise 13–18% of regional high priority forestland and 24–28% of the high priority lands owned by the federal government. Interestingly, a larger proportion of high biodiversity priority lands and a smaller portion of high carbon priority lands is in private ownership (Fig. 5). Across targets, there is minimal difference in who owns forestlands needed to achieve 30% or 50% forest preservation targets. There are also minimal differences regardless of whether forestlands with high future vulnerability to droughts and fires were not masked from analysis (Supplementary Figs. 3–5).

Forest ownership of high preservation priority forestlands differs among states. Private entities own over 25% of high preservation priority forestland in California, Colorado, Oregon, Utah, and Washington. Tribal governments own ~45% of high preservation priority forestland in Arizona, by far the highest of any state in the region (Supplementary Figs. 1 and 2). Again, across targets by state, there is minimal difference in ownership of forestlands needed to achieve 30% or 50% forest preservation targets.

Forest carbon, habitat, and surface drinking water added by protected area scenarios. Protected forestlands (GAP 1 and 2) currently (2000–2009) store ~2.25 Pg C, or 20% of the total forest ecosystem carbon in the western US (~11.34 Pg C; Fig. 6a, Supplementary Fig. 6). These protected forests could accumulate another ~0.45 Pg C by 2050 as they continue to grow and mature (Fig. 6b, Supplementary Fig. 6). Depending on preservation priority, if 30% of forestlands were preserved, they would currently store 3.60–3.94 Pg C (32–35% of total) and could accumulate another 0.74–0.91 Pg C by 2050. Similarly, if 50% of forestlands were preserved, they would currently store 5.78–6.21 Pg C (51–56% of total) and could accumulate another 1.20–1.47 Pg C by 2050. Preserving 50% of forestlands would triple the amount of carbon that is currently protected. Prioritizing jointly for carbon and biodiversity leads to only slightly (2–4%) lower preservation of current carbon stocks and near-future carbon accumulation compared with prioritizing for carbon alone.

Generally, less than 20% of each animal and tree species' forest habitat is currently protected (GAP 1 or 2) in the region (Fig. 7a). The median percentage of forest habitat currently preserved for amphibian, bird, mammal, and reptile species is ~18% for each taxa and 14% for tree species. If prioritized jointly for carbon and biodiversity, then preserving 30% of forestlands would increase median forest habitat protection to ~30% for species of each taxa, while preserving 50% of forestlands would further increase this to ~50% for species of each taxa (Fig. 7b). If 50% of forestlands were preserved, then most (82–95%) animal and tree species would

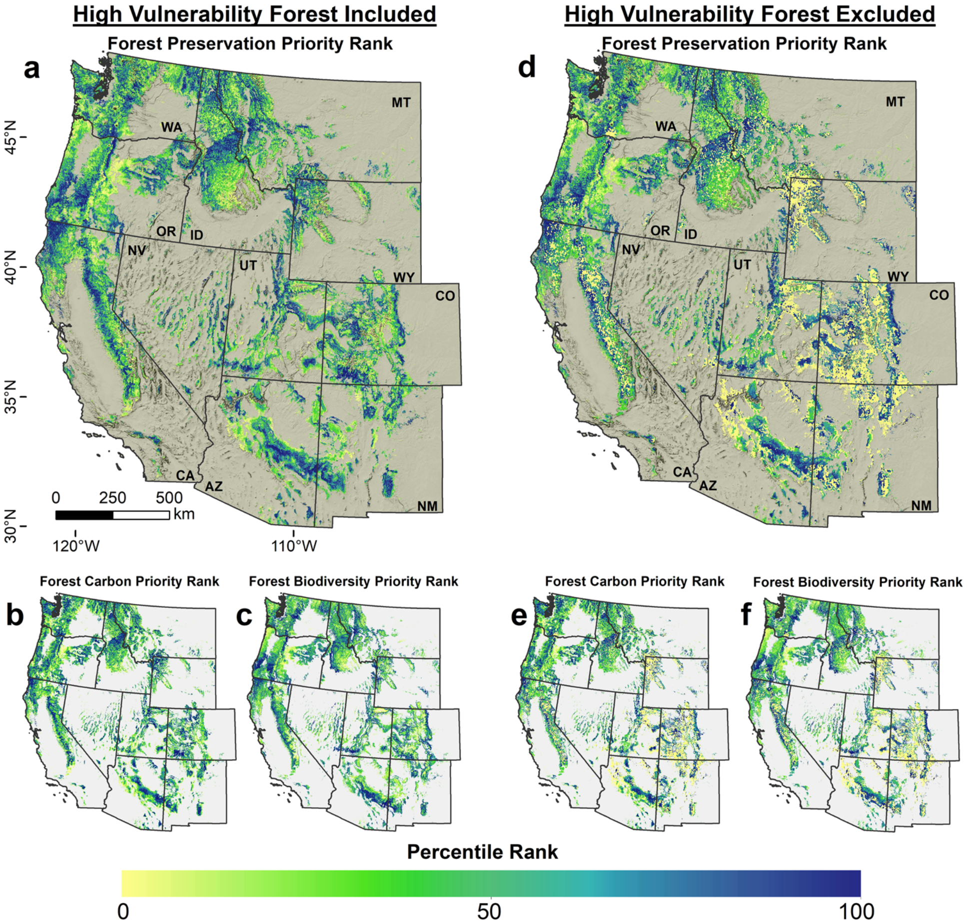

Fig. 3 Forest preservation, carbon, and biodiversity priority ranking for the western US. a, **d** Forest preservation priority ranks were derived from **b**, **e** forest carbon priority ranks and **c**, **f** forest biodiversity priority ranks for each ecoregion within every state. High future vulnerability to drought or fire could destabilize forest carbon and biodiversity, thus priority ranks were computed when both including (left columns) and excluding (right columns) forestland with high future vulnerability as simulated with CLM4.5.

have at least 30% of their forest habitat protected. Prioritizing jointly for carbon and biodiversity leads to slightly lower forest habitat protection than if prioritized only for biodiversity.

Threatened or endangered species would also benefit from increased forest preservation. For instance, currently ~26% and ~22% of gray wolf (*Canis lupus*) and Canada lynx (*Lynx canadensis*) forest habitat is protected in the region, but ~36 and 33% would be protected if 30% of forestlands were preserved. Furthermore, currently ~14% and ~15% of marbled murrelet (*Brachyramphus marmoratus*) and spotted owl (*Strix occidentalis*) regional forest habitat is protected, but ~28% and ~31% would be protected by reaching this preservation target. Protecting 50% of forestlands would lead to over half of these species' regional forest habitat being preserved.

Forestlands account for 56% of the most important areas (top 75%) for surface drinking water in the region (Supplementary Table 4). Only ~19% of the most important forestlands for surface drinking water are currently preserved as GAP 1 or 2. However, reaching 30% or 50% forest preservation targets would mean preserving about 33 and 53%, respectively, of the forestlands that are most important for surface drinking water, after excluding high vulnerability forests.

Discussion

Preservation is crucial for mitigating ongoing climate change and stemming loss of biodiversity[10,12,30], thus international efforts are underway to protect 30% of land and water by 2030 (30 × 30) and 50% by 2050 (50 × 50). Here we assessed current preservation in the western US and show that 13.4% (41.08 Mha) of land area is protected (GAP 1 or 2; IUCN Ia-VI), including 18.9% (17.48 Mha) of regional forestland (Table 1). To meet the 30 × 30 or 50 × 50 targets in this region, an additional 10.3 Mha or 28.8 Mha of forestland would need protection. We developed and applied a geospatial framework to explicitly identify forestlands that could be strategically preserved to help meet these targets. We propose that Strategic Forest Reserves could be established on federal and state public lands where much of the high priority forests occur, while private entities and tribal nations could be incentivized to preserve other high priority forests. We further find that preserving high priority forests would help protect (1) ecosystem carbon stocks and accumulation for climate mitigation, (2) animal and tree species' habitat to stem further biodiversity loss, and (3) surface drinking water for water security. Progress has been made, but much work needs to be done to reach the 30 × 30 or 50 × 50 targets in the western US.

To meet preservation targets, new permanent protections are needed at the highest levels for forests in the western US. Permanent protection is best met on federal and state public lands with additional land designated as wilderness areas, wild and scenic rivers, and national monuments, and by a new category of Strategic Forest Reserves for climate mitigation and adaptation. We found that about 65% of regional high priority forest occurs on federal and state lands, highlighting important roles for federal

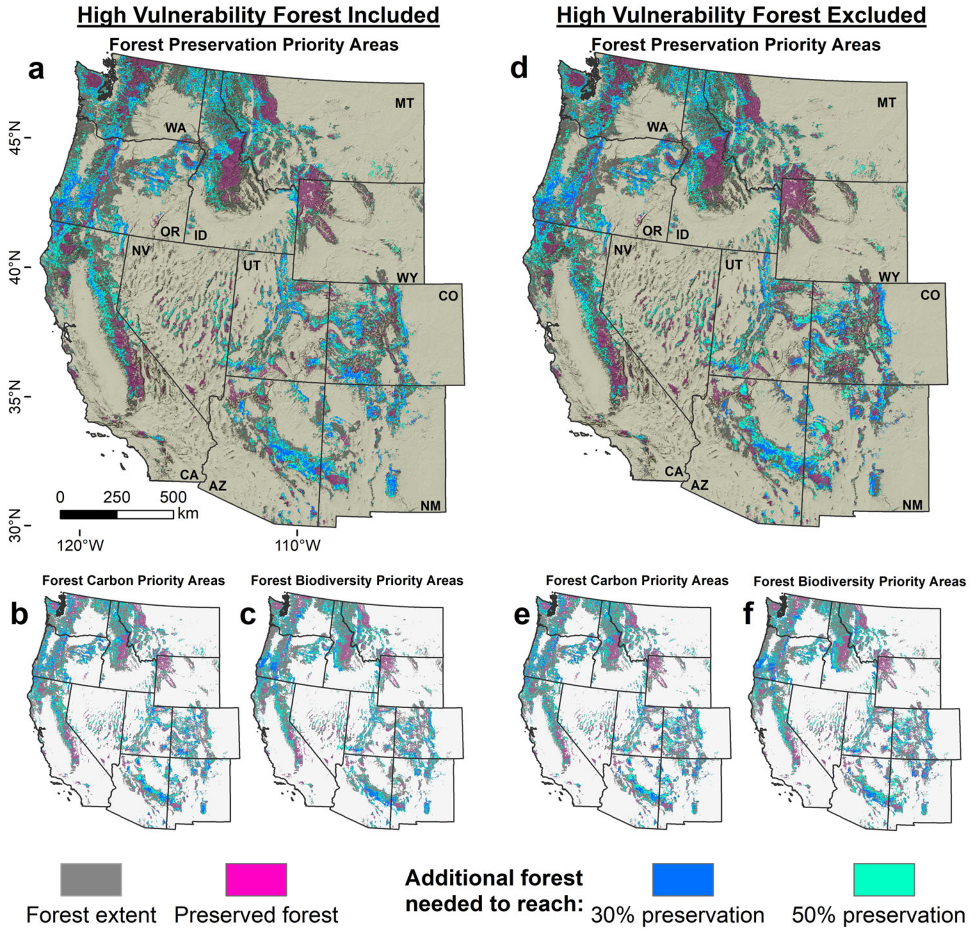

Fig. 4 Currently preserved forestlands and additional forestlands identified to meet preservation targets across the western US. Preservation targets include preserving 30 and 50% of forestland in each state. Preservation priority areas are presented for three scenarios that include **a**, **d** overall forest protection priority, as well as constituent **b**, **e** forest carbon priority and **c**, **f** forest biodiversity priority. High future vulnerability to drought or fire could destabilize forest carbon and biodiversity, thus protection priority areas were identified when both including (left columns) and excluding (right columns) forestland with high future vulnerability as simulated with CLM4.5. These forest priority areas were identified by sequentially combining the highest ranked forestlands within each state (Fig. 3) until each protection target was met. Currently protected forestlands shown here are GAP 1 and 2.

Table 2 Forestland simulated to have high future vulnerability to fire, drought, and fire or drought (sum) from 2020 to 2050 for each state in the western US.

State	Forest		High future vulnerability to...					
			Fire		Drought		Either	
	Mha	%	Mha	%	Mha	%	Mha	%
AZ	7.67	26.0	0.14	1.8	2.80	36.5	2.93	38.2
CA	11.97	29.3	2.42	20.2	0.07	0.6	2.49	20.8
CO	9.50	35.2	2.09	22.0	2.84	29.9	4.77	50.2
ID	9.53	44.0	1.22	12.8	0.19	2.0	1.41	14.8
MT	9.57	25.1	1.59	16.6	0.11	1.1	1.70	17.8
NM	6.74	21.4	1.22	18.1	2.00	29.7	3.10	46.0
NV	3.60	12.6	0.03	0.8	0.65	18.1	0.68	18.9
OR	12.68	50.5	0.57	4.5	0.19	1.5	0.75	5.9
UT	6.93	31.5	0.77	11.1	1.73	25.0	2.41	34.8
WA	10.00	57.4	0.22	2.2	0.01	0.1	0.23	2.3
WY	4.27	16.9	1.56	36.5	0.67	15.7	2.22	52.0
Region	92.46	30.1	11.82	12.8	11.28	12.2	22.71	24.6

Forest vulnerability was assessed using simulations from the Community Land Model 4.5 conducted as part of an earlier study[25].

and state governments. We also found that private entities and tribal nations own about 25 and 10%, respectively, of regional high priority forest. Strategic Forest Reserves could be established on federal lands through executive action, regulation and rule-making and could be a low-cost way to simultaneously meet goals of protecting climate and biodiversity. Private and tribal lands present substantial opportunities for increasing carbon storage and protecting biodiversity through incentives, voluntary conservation measures, and fair market acquisition. To help meet preservation targets, federal and/or state governments could fund private entities and tribal nations to establish permanent conservation easements that protect carbon rich and biodiverse forests from resource extraction. Federal and state governments must lead efforts to protect forest carbon and biodiversity, though private entities and tribal nations could make important contributions to these efforts in the western US.

To qualify for inclusion in meeting preservation targets, lands should have protection that meets GAP 1 or 2 standards. These standards include permanent protection from conversion of natural land cover and a binding management plan that provides for maintaining a natural state (Supplementary Table 1). Lowering the standard of land protections to include GAP 3 or GAP 4 has gained interest, but it comes with a cost to species and

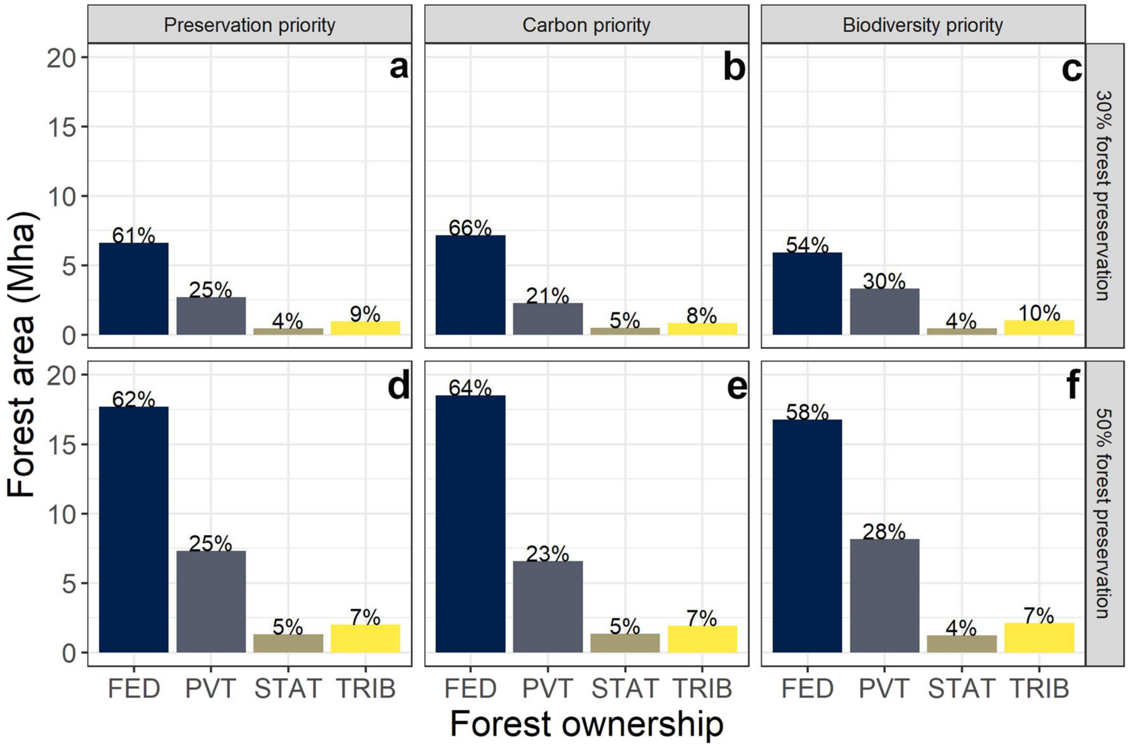

Fig. 5 Current ownership of forestlands in the western US needed to achieve two preservation targets. Forest ownership is presented for each preservation target (rows) and priority (columns). Preservation targets include **a**–**c** 30% and **d**–**f** 50%. Preservation priorities include **a**, **d** overall forest protection priority, **b**, **e** forest carbon priority, and **c**, **f** forest biodiversity priority. Forest owners include the U.S. Federal Government (FED), Private (PVT), State Governments (STAT), and Tribal Governments (TRIB). The figure excludes ownership classes that hold <2% of high preservation priority forestland (e.g., Non-Governmental Organizations). State-level summaries are provided in Supplementary Figs. 1 and 2. Similar patterns are evident when forestlands with high future vulnerabilities are included in the analysis (Supplementary Figs. 3–5). Land ownership data from the PAD-US[20].

ecosystem resilience. For example, livestock grazing covers a large portion (121 Mha) of federal public lands in the region[31,32] and causes a major decrease in biodiversity due to processes such as degradation and competition[33]. Logging also has deleterious impacts on biodiversity[34] and is a large source of carbon emissions in the western US, particularly in the Pacific Northwest[35,36]. Lands used to meet preservation targets should have the same level of protection as Wilderness areas without grazing, and be permanently protected from roads, logging, and other development. Wilderness areas are cost-effective cornerstones of intact landscapes that provide clean water, fish and wildlife habitat, and climate change mitigation, while also supporting sustainable recreation economies worth billions of dollars annually[28,30]. Recreation can be compatible with permanent protection so long as it does not include use of off-highway vehicles that have done considerable damage to ecosystems, fragmented habitat, and severely impacted animals including threatened and endangered species[37]. Forestlands used to meet preservation targets should be managed for preservation of biodiversity, carbon, and water supplies by preserving older, mature forests and limiting resource extraction.

It is possible to elevate the preservation status of GAP 3 areas on federal lands by phasing out livestock grazing, mining, and logging and strengthening protection via administrative rule. Inventoried Roadless Areas (IRAs) are key GAP 3 federal areas that have already been identified and are available for permanent protection. The National Forest System (NFS) includes approximately 16.8 Mha of IRAs in the western US, or 71% of all IRAs on NFS lands in the nation[38]. These are among the most wild and undeveloped areas not only in the nation but also within their respective states[38]. We found that IRAs comprise 13–18% of regional high priority forest and 24–28% of the high priority forest owned by the federal government, underscoring the crucial biodiversity and carbon benefits that these forests provide. IRAs currently provide clean drinking water for millions of people, support salmon populations and wildlife, and reduce isolation between protected areas[39,40]. However, IRAs are an administrative designation of the USFS and not legislatively established by the US Congress, thus they are not considered part of the US system of protected areas (GAP 1 or 2)[38]. There is also large potential to meet preservation targets by protecting uninventoried roadless areas (e.g., ~2 Mha in Oregon), many of which are candidates for protection and contiguous with IRAs or existing protected areas.

Forest protection is the lowest cost climate mitigation option. Forest carbon accumulation should not be considered as an offset that allows additional fossil fuels to be burned. This is a weakness of current "net zero" accounting that should be modified by separating emissions reduction from carbon removal from the atmosphere[41]. Accounting and incentives could be applied to each approach to ensure the targets are met at local to international scales.

Establishment of Strategic Forest Reserves on non-federal public and private land could have important implications for international climate change mitigation agreements. For example, the Paris Agreement encourages trade in offsets. The trade in offsets has set up some potential problems, particularly when offsets are secured by storing more carbon on non-federal public land and private land but tallied twice, once when traded in markets (especially by international emitters) and again when reported in the national reporting instruments, such as NDC stock taking. Although the Paris Agreement is clear that double-counting must be avoided under Article 6,

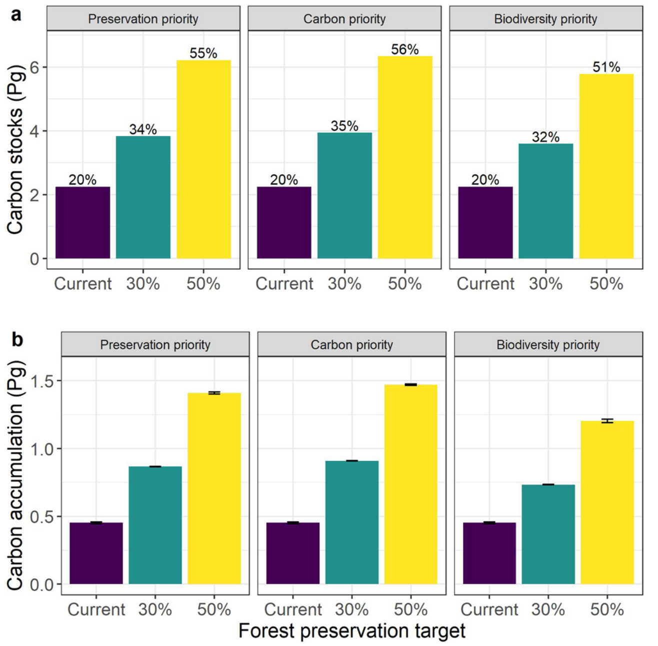

Fig. 6 Forest ecosystem carbon stocks and near-term carbon accumulation in current and potentially preserved forestlands by preservation target and priority. **a** Forest ecosystem carbon stocks including carbon in live and dead trees and soil. Black text above each bar denotes the percentage of total region-wide carbon stocks that is currently or would be preserved by reaching the preservation targets. **b** Forest carbon accumulation from 2020 to 2050 simulated using CLM4.5 forced by the IPSL and MIROC climate models assuming no harvest on preserved forestlands. Bars denote multi-model average carbon accumulation and error bars show the range among simulations. **a**, **b** The forestlands contributing to the preservation targets (e.g., 30%, 50%) include currently protected forestland. Currently preserved forestlands shown here are GAP 1 and 2. The forest ecosystem carbon stock data are from the USFS FIA[23] and the forest carbon accumulation data are from Buotte et al.[66].

the extent that double-counting is avoided depends on how accounting rules are operationalized. If emissions reductions are double-counted, it results in an increase in global emissions. If 40% of reserve actions are taken on non-federal public land and private land, this may have implications for emerging voluntary markets as the increased demand in markets could depress the value of those options. While economic and accounting issues are beyond the scope of this study, they exist and need to be addressed as policy commitments are made.

Our study shows that strategically increasing the extent of forest protection would help safeguard climate, biodiversity, and drinking water in the western US. Forest protection is needed to prevent forest loss and degradation, reduce greenhouse gas emissions, and maintain large carbon sinks. Avoiding loss and restoring carbon- and species-rich ecosystems is of highest importance for combined climate change mitigation and biodiversity protection[8]. We find that currently only ~20% of regional forest carbon stocks are in protected areas but that ~35% of carbon stocks could be protected by meeting the area-based 30 × 30 target. Protecting existing forest carbon stocks[42] and allowing forests to continue to grow are effective means of preventing carbon emissions and removing carbon dioxide from the atmosphere (Supplementary Fig. 7)[11,12,36,43]. Protecting high priority forests also creates co-benefits for adaptation to climate change for people and nature, such as higher genetic, species, and ecosystem diversities, resilience to climate extremes, and increased water availability[28].

Preserving high priority forests across the region would increase the amount of protected habitat for animal and tree species and promote landscape connectivity, thus helping maintain viable populations and ecological functions for climate adaptation[44,45]. We found that generally less than 20% of each animal and tree species' regional forest habitat is currently protected, yet this could increase to ~30% and ~50% for each species if the 30 × 30 and 50 × 50 targets were met by preserving high priority forests. To ensure increased protection for the many facets of regional biodiversity, we prioritized forests for preservation within each ecoregion because these delineate distinct biotic (e.g., vegetation, wildlife) and abiotic (e.g., soils, climate) conditions[46,47]. Distributing protection across ecoregions also promotes regional connectivity. Nevertheless, our current analysis did not incorporate metrics of forest connectivity[39] or fragmentation[48], thus isolated forest "patches" (i.e., one or several grid cells) were not ranked lower for preservation priority than forests that were part of large continuous corridors. Similarly, forest heterogeneity within each 1 km grid cell was not considered. Extensive road systems are common on private and federal public lands and fragment large expanses of forest that are recovering from a century of high-grade logging[48]. Many of these fragmented forests are nevertheless important for carbon and biodiversity. Further efforts could combine landscape metrics with the forest PPR system to incorporate effects of connectivity and fragmentation (e.g., values of large contiguous patches versus smaller isolated patches of forest) on forest preservation priority. To best preserve biodiversity, new protected areas should be well-distributed across the region, include climate refugia[49,50], and have connecting corridors and road crossings to facilitate species movement and gene flow[39,44,51].

Climate and land use change have contributed to animal population declines in the western US[34,52], leading to an increase in species listed under federal protection[53]. These environmental changes contributed to declining bird populations in about half of assessed species ($n = 108$) across the western US since the 1980s (mean trend = −0.84% per year)[34]. For instance, destruction and fragmentation of old-growth forest habitat caused marbled murrelet and spotted owl populations to decline in the Pacific Northwest, leading them to be state and federally listed[54,55]. We find that only ~15% of their forest habitat is currently protected and that preserving high priority forests would protect additional habitat that could aid population recovery. In addition to birds, large threatened carnivores such as gray wolves and Canada lynx would benefit from expanding regional forest protection. Gray wolves are a keystone species in the region and can trigger trophic cascades to plants with beneficial effects for biodiversity and streams[56]. Canada lynx is a cold-adapted species and increases in temperature and wildfires threaten their persistence in parts of the western US[57]. Animals at the southern edge of their species ranges may be particularly vulnerable to warming and thus protection of additional forest habitat may allow them to persist in higher elevations and move northward to a climate more suitable for survival[57]. Expanding forest protection to meet preservation targets could help stem loss of regional biodiversity.

Besides safeguarding climate and biodiversity, preserving high priority forests would help protect clean water, thus providing a crucial ecosystem service given mounting concerns over water security in the western US[58,59]. Anthropogenic warming is contributing to a megadrought in the Southwest[60] and lower mountain snowpack across much of the region[61], with future warming expected to exacerbate water insecurity[58,59,62]. We found that despite covering only 30% of the region, forests account for over half of the most important (top 75%) areas for regional surface drinking water. However, only 19% of these specific forestlands are currently protected (GAP 1 or 2). Forests

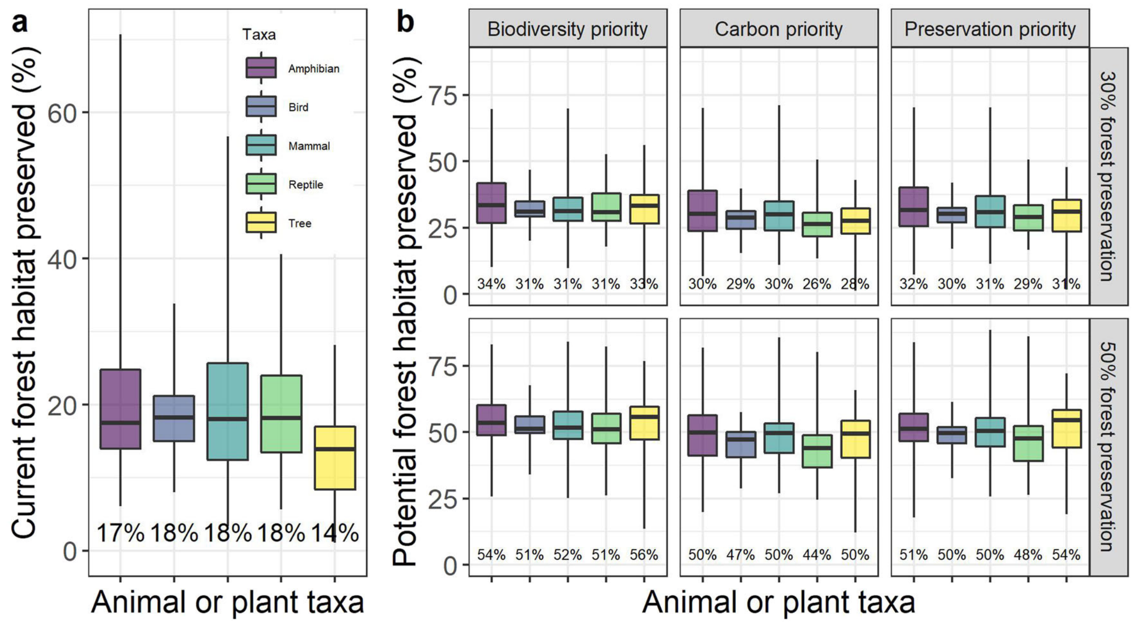

Fig. 7 Current and potential forest habitat preservation for animal and plant species summarized by taxa. **a** The percentage of each species' regional forested habitat that currently occurs on protected (GAP 1 or 2) forestlands in the western USA, grouped by taxa. **b** The percentage of each species' forested habitat that would be preserved based on several preservation targets (i.e., 30% or 50%) and priorities (i.e., carbon and/or biodiversity). Data for animal species habitat from the USGS GAP[21] and for tree species habitat from the USFS FIA[23]. For each boxplot, the intra-box line depicts the median, while the box extends from the 25th to 75th percentiles, and the whiskers extend from the 5th to 95th percentiles. Black text within each box denotes the median percentage of protected habitat across species of that taxa.

help ensure surface drinking water quality[63,64] and thus meeting the preservation targets would provide co-benefits for water security in an era of growing need.

Forest vulnerability to future drought and fire should be considered when identifying areas for biodiversity and climate protection[18,25,65]. Drawing on prior mechanistic model simulations from CLM4.5[25,66], we find the highest forest vulnerability is likely to occur in parts of the Southwest (e.g., New Mexico, Arizona, Colorado; 2.98–4.77 Mha forest) whereas the lowest forest vulnerability occurs in the Pacific Northwest (e.g., Oregon, Washington; 0.23–0.75 Mha forest). The Southwest is projected to become increasingly hotter and drier over the coming century, leading to continued increases in wildfire and drought-induced tree mortality that could destabilize forest carbon and biodiversity[25,62,67–69]. Lower forest vulnerability in the Pacific Northwest means that permanence of protection is more likely to be achieved. From a policy perspective, highly vulnerable forests might not be high priorities for preservation because of potential shifts from forest to non-forest, though from a biodiversity perspective it is important to recognize that maintaining protection of these vulnerable forests may encourage species persistence in topographically complex climate refugia and facilitate species migration to areas that may be more suitable for survival[49].

Wildfire is an important ecological process and together with climate change is a key driver of ecosystem change. Annual burn area increased in the western US over the past three decades due to warming and drying[70,71] and more human-caused ignitions[72]. As warm dry ecoregions continue to get warmer and drier[60,62], the fire regime may change to large high-severity fires that could convert more structurally homogeneous dry forests to non-forest ecosystems[73]. In other ecoregions, fires may continue as a patchwork of mixed severities[74] that is better for forest regeneration and biodiversity[75]. Moreover, mixed-severity fires mostly combust surface litter, duff, shrubs and small trees[76], with regional fires leading to lower carbon losses than harvest or beetles[35,77,78]. Differences in fire regimes among ecoregions are important parts of the decision-making process. For example, forests in parts of Montana and Idaho are projected to be highly vulnerable to future wildfire but not drought, thus fire-adapted forests climatically buffered from drought may be good candidates for preservation. Moist carbon rich forests in the Pacific Coast Range and West Cascades ecoregions are projected to be the least vulnerable to either drought or fire in the future[25], though extreme hot, dry, and windy conditions led to fires in the West Cascades in 2020. It is important to recognize that forest thinning to reduce fire risk has a low probability of success in the western US[73], results in greater carbon losses than fire itself, and is generally not needed in moist forests[79–82]. Predicting future occurrence and timing of large disturbance events remains difficult, thus to better inform land management, efforts are needed to improve the ability of terrestrial biosphere models to simulate fire, drought, and other ecosystem processes[83,84].

In summary, we not only show that additional forest protection is needed to meet preservation targets (i.e., 30 × 30, 50 × 50) in the western US, but also determine where it would be most effective to preserve additional forest for climate mitigation and adaptation goals that minimize further species loss and ecosystem disruption. Our prioritization framework helps ensure preservation opportunities are distributed across the region, thereby protecting many facets of regional biodiversity, promoting connectivity, and providing local opportunities for engagement in decision-making. Drought and wildfire are becoming more common in this region and could destabilize forest carbon and biodiversity in some areas; thus, our framework incorporates ecosystem model simulations to identify forests with high future vulnerability and reduces their priority for protection. Meeting preservation targets would increase protection of forest carbon stocks and accumulation, animal and tree species' habitat, and surface drinking water in the western US. We focus on forestlands, but note these lands often include a mosaic of non-forest ecosystems (e.g., grasslands, wetlands, shrublands) that are also important for biodiversity preservation and carbon storage and accumulation.

Developing a broader landscape PPR system that includes non-forest ecosystems would require standardized spatial datasets related to current ecosystem carbon stocks (e.g. ref. [85]), habitat distribution for non-woody plant species and ideally invertebrate species, and multi-taxa simulations of potential future ecological dynamics. To help inform efforts to meet preservation targets, our new forest prioritization datasets can be combined with local knowledge and finer-scale local analyses using higher resolution spatial datasets. Next steps are to apply this framework across countries, include non-forest ecosystems, simulate future ecological conditions at higher spatial resolution, and account for how preservation prioritization is affected by uncertainty in underlying geospatial datasets. Natural climate and biodiversity solutions will be most effective when simultaneously implemented with ambitious reductions in all human-caused greenhouse gas emissions.

Methods

General data processing and analysis. An important step in spatial conservation prioritization is selecting a spatial resolution. High spatial resolution prioritization is needed to inform land management but spatial resolution is often constrained by the availability of existing species and ecosystem datasets[86]. We derived the forest PPR using existing spatial datasets that were originally gridded at 30 m, 250 m, and 4000 m spatial resolution over the 92.46 Mha (924,600 km^2) of forest land in the western US (Table 3). The coarsest resolution datasets were CLM4.5 simulations of future carbon accumulation and vulnerabilities from 2020 to 2050[18,66]. It is crucial to consider future carbon accumulation and vulnerabilities when evaluating potential contributions of forests to climate change mitigation and biodiversity protection[18,65]; however, CLM4.5 and other land surface model simulations are very computationally intensive and rarely available even at a 4000 m spatial resolution. The CLM4.5 simulations were thus the primary factor constraining the spatial resolution of our analysis. We selected a 1 km spatial resolution for this analysis as a balance between the fine resolution (30–250 m) and coarse resolution (4000 m) datasets currently available. While a finer spatial resolution (e.g., 250 m) would have been preferable, we were not confident that future forest carbon accumulation or vulnerabilities would be adequately captured by further downscaled CLM4.5 simulations. Moreover, a 1 km resolution is amenable to large-scale conservation planning that considers multiple facets of biodiversity and ecosystem function across a subcontinent and lends itself to comparisons with other conservation prioritization datasets produced at 1 km resolution (e.g. ref. [39]). We performed the spatial analysis on a 1 km resolution grid in an Albers Equal Area projection using the statistical software R (version 4.0)[87]. Data were processed using *raster*[88], *rgdal*[89], and *gdalUtils*[90], handled using *data.table*[91], and visualized using *ggplot2*[92] libraries. Maps were created using Esri ArcMap 10.8 software.

Assessing current preservation status of regional forests relative to preservation targets. We assessed the current extent and preservation status of forestland in the western US, as well as the additional forestland that would need to be protected to reach 30 and 50% preservation targets. We characterized the current forest extent using a 250 m resolution forest type dataset created by the United State Forest Service (USFS) Forest Inventory and Analysis (FIA) program using forest inventory, MODIS satellite, and ancillary geospatial datasets[19]. We characterized land preservation status using the Protected Areas Database of the United States (PAD-US version 2.1). The PAD-US is the official national inventory of protected areas in the United States and is produced by the USGS GAP[20]. The PAD-US includes spatial information on the known protected areas for public and private lands in all 50 states, along with the status of each protected area according to guidelines developed by the International Union for the Conservation of Nature (IUCN). Conservation status is characterized by GAP status codes that describe management intent to conserve biodiversity. GAP 1 and 2 signify areas with permanent protection from anthropogenic land cover conversion and management plans to maintain a fully or primarily natural state. The GAP 1 generally corresponds to IUCN Category Ia, Ib, and II, and GAP 2 to IUCN Categories III through VI (Supplementary Table 1). We clipped the forest extent and PAD-US datasets to the region, majority aggregated forest extent to 1 km resolution, and gridded the PAD-US GAP status code at 1 km resolution using the lowest GAP status in the case of overlap. We then assessed the total land and forest area of each state that currently has permanent protection (GAP 1 or 2). Moreover, we computed the additional area needed if the goal is to protect 30 and 50% of total land and forest area in each state.

Prioritizing forestlands for preservation based on carbon and/or biodiversity. After identifying the additional forest area needed to reach 30 and 50% preservation targets, we then sought to prioritize unprotected forestlands for preservation based on carbon and/or biodiversity (three scenarios). We derived both carbon and biodiversity priority ranks for each forested grid cell in the region and also derived a forest preservation priority rank ("forest PPR") for each grid cell that incorporated metrics of both forest carbon and biodiversity.

We defined forest carbon metrics that included both current forest ecosystem carbon stocks and simulated near-future forest carbon accumulation from 2020 through 2050. The USFS FIA mapped forest ecosystem carbon stocks at 250 m resolution across the contiguous U.S. using inventory plot, MODIS satellite, and ancillary geospatial datasets[23]. This dataset reflects forest conditions during the period from 2000 to 2009 and is the most recent spatial dataset on forest ecosystem carbon stocks available from the USFS FIA. We determined current forest carbon stocks for each 1 km grid cell by summing the carbon stocks of the 16 underlying 250 m resolution grid cells.

Forest carbon accumulation was simulated across the western US from 1979 to 2099 by Buotte, et al.[25] using a modified version of the CLM4.5[24]. The CLM is the land surface component of the Community Earth System Model[93], and calculates multiple biophysical and biogeochemical processes, including surface heat fluxes, photosynthesis, evaporation, transpiration, carbon allocation to plant tissue, decomposition, and nitrogen cycling. The CLM4.5 was modified to represent 13 coniferous forest types commonly found in the region, and to allow soil moisture stress to increase leaf shed[25]. Forest carbon cycling was simulated at ~4 km resolution for two time periods: 1979–2014 and 2015–2099. The historical simulations (1979–2014) were performed using historical CO_2 concentrations, climate, and harvest such that the simulations represent present-day stand ages. The future simulations (2015–2099) were forced by downscaled climate data from the IPSL-CM5A-MR and MIROC5 general circulation models following representative concentration pathway 8.5 concentrations of anthropogenic greenhouse gas emissions. Previous comparisons between simulation output and observational data sets showed that simulated aboveground carbon was highly correlated ($R^2 > 0.80$) with observation-based estimates across forest types and ecoregions[25]. Potential future forest carbon accumulation was estimated by running the CLM4.5 with no harvest after 2014 and then summing annual net ecosystem production from 2020 onward, thus allowing forest carbon accumulation to be determined by forest type, soil properties, climate, and wildfires. We estimated potential forest carbon accumulation for each 4 km grid cell by summing annual net ecosystem production from 2020 to 2050 and then disaggregated these data to 1 km resolution for analysis.

We defined metrics of biodiversity using tree species richness and terrestrial vertebrate species richness by taxa. The USFS FIA mapped live tree basal area for 324 tree species at 250 m resolution across the contiguous U.S. using inventory plot data along with MODIS satellite and environmental datasets[22]. This is a subset of the over 1000 tree species found in the USA. The USGS GAP modeled current habitat distribution for 1718 terrestrial vertebrate species at 30 m resolution across the contiguous U.S. using a suite of geospatial predictors[21]. This nominally includes

Table 3 Spatial datasets used to derive the forest preservation priority ranking system.

Category	Metric	Period	Original resolution (m)	Reference
Ecosystem	Ecoregions (level 3)	--	--	46
	Forest extent	2000–2004	250	19
Biodiversity	Amphibian species habitat ($n = 97$ species)	2000	30	21
	Bird species habitat ($n = 483$ species)	2000	30	21
	Mammal species habitat ($n = 339$ species)	2000	30	21
	Reptile species habitat ($n = 170$ species)	2000	30	21
	Tree species habitat ($n = 78$ species)	2000–2009	250	22
Carbon	Forest carbon stocks	2000–2009	250	23
	Forest carbon accumulation	2020–2050	4000	25
Vulnerability	Vulnerability to drought	2020–2050	4000	25
	Vulnerability to fire	2020–2050	4000	25

all terrestrial amphibian, bird, mammal, and reptile species found during summer and/or winter in the contiguous U.S., though stopover habitats for migratory species are not included. We selected the tree and vertebrate species that occurred in the study domain, converted live tree basal area to species presence or absence, and then aggregated each species habitat map to 1 km resolution such that a grid cell was considered to have habitat if it included any modeled habitat at a finer spatial resolution. For each species, we masked out habitat on non-forestlands, resulting in our analysis including 78 tree species and 1089 terrestrial vertebrate species. We then estimated tree and vertebrate taxa (e.g., amphibian) species richness by counting the number of species with habitat in each forested grid cell. We did not include terrestrial invertebrates, non-woody plants, or non-vascular plants because there was not the necessary spatial data.

Recognizing the importance of spatially distributed preservation[11], we computed forest carbon, biodiversity, and preservation priority ranks for each grid cell relative to other grid cells in the same ecoregion within each state. There are 35 level III ecoregions in our study domain that represent land areas with distinct biotic (e.g., vegetation, wildlife) and abiotic (e.g., soils, climate) conditions[46]. The forest carbon priority ranks were derived by computing for each grid cell the percentile ranks of current ecosystem carbon stocks and near-future carbon accumulation, summing the resulting ranks, and then re-ranking grid cells based on these summed ranks. The forest biodiversity priority ranks were derived in a similar manner using vertebrate and tree species richness ranks, with vertebrate species richness ranks computed from the ranked sum of percentile ranks for each vertebrate taxa (i.e., amphibians, birds, mammals, and reptiles). Finally, the forest preservation priority rank was derived for each grid cell as the ranked sum of forest carbon and biodiversity priority ranks.

Ongoing warming and drying could increase forest vulnerability to drought or fire in parts of the western US thereby destabilizing forest carbon and biodiversity[25,65]. Water-limited forests in the Rocky Mountains, Southwest, and Great Basin regions were expected to be the most vulnerable to future drought-related mortality and the Sierra Nevada and portions of the Rocky Mountains were expected to be most vulnerable to fire in the next decades[25]. Therefore, we derive and compare preservation priority rankings with and without forests with high future vulnerability to drought or fire.

Determining ownership of forestlands with high preservation priority. We determined who currently owns unprotected forestlands that have the highest priority for meeting preservation targets. The PAD-US (version 2.1) dataset includes the geographic boundaries of public lands and their ownership (e.g., Federal Government, State Government), as well as of private conservation lands that are voluntarily provided by authoritative sources[20]. This dataset does not include the geographic boundaries of other private lands, but these boundaries are included in an older, off-shoot version of the dataset created by the Conservation Biology Institute (CBI) (i.e., PAD-US CBI Edition version 2)[94]. We gridded both versions of the PAD-US dataset at 1 km resolution and filled data gaps in the PAD-US using the PAD-US CBI Edition. The PAD-US also is occasionally missing information on who owns public lands but the database generally has information on their management type. In these cases, we filled unknown ownerships with the corresponding management type. We then extracted ownership information for each grid cell that was identified as having high priority for meeting each preservation target and priority. Lastly, for each preservation target and priority we computed the total area of these high priority forestlands that occurred in each ownership category.

Evaluating how meeting preservation targets contributes to protecting forest carbon, biodiversity, and surface drinking water. We evaluated current protection (GAP 1 or 2) of forest carbon, biodiversity, and important areas for surface drinking water as well as how protection would increase by meeting each preservation target if forests were prioritized for carbon and/or biodiversity. Specifically, we estimated total current ecosystem carbon stocks and potential near term carbon accumulation (2020–2050) for currently protected forestlands and if preservation targets were met following each prioritization scenario. We again relied on carbon stock and accumulation datasets from the USFS FIA[23] and Community Land Model 4.5 simulations[66], respectively. For biodiversity, we determined the current amount of each animal and tree species' habitat[21,22] that occurs in regional forestlands, as well as the percentage each species' forest habitat that is currently protected. We then determined how much of each species' forest habitat would be protected by reaching the preservation targets using each prioritization scenario and summarized these data by taxa (i.e., amphibians, birds, mammals, reptiles, and trees). We also assessed how meeting the preservation targets would contribute to protection of forest habitat for four select threatened animal species, including grey wolves (*Canis lupus*), Canada lynx (*Lynx canadensis*), marbled murrelet (*Brachyramphus marmoratus*), and spotted owl (*Strix occidentalis*). Moreover, we assessed current and potential protection of the most important areas (top 75%) for surface drinking water in the region using the Forests to Faucets (version 2) dataset from the USFS[95]. The USFS estimated surface drinking water importance for each of the country's sub-watersheds based on surface water supply, flow paths, and consumer demand. We clipped this dataset to the study domain, rasterized the Important Areas for Surface Drinking Water attribute at 1 km resolution, and identified the most important areas (top 75%) for surface drinking water in the region. We then used spatial overlays to assess the extent to which the most important areas occurred on current protected forestlands and potential future protected lands under each preservation target and prioritization scenario.

Data availability

The forest preservation priority datasets generated as part of this research are publicly archived with PANGAEA (https://www.pangaea.de/). The datasets that support the findings of this study are publicly available. The Protected Area Database of the United States (PAD-US v. 2.1) dataset is available from the USGS (https://www.sciencebase.gov/). The forest extent dataset is available from the USFS (https://data.fs.usda.gov/geodata/). The forest ecosystem carbon stock dataset is available from the USFS (https://doi.org/10.2737/RDS-2013-0004). The CLM4.5 forest carbon cycle simulations are available from the ORNL DAAC (https://doi.org/10.3334/ORNLDAAC/1662). The vertebrate species habitat data are available from the USGS (https://gapanalysis.usgs.gov). The tree species basal areas data are available from the USFS (https://doi.org/10.2737/RDS-2013-0013). The surface drinking water data are available from the USFS (https://www.fs.fed.us/ecosystemservices/FS_Efforts/forests2faucets.shtml).

Code availability

All custom scripts written for this analysis are publicly archived on GitHub (https://github.com/ecospatial-services/wus_forest_conservation).

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B.E.L., L.T.B., and P.C.B. designed the study. Community Land Model output was provided by P.C.B. Data acquisition, analysis, and visualization were conducted by L.T.B. Ideas were contributed by W.J.R. and D.J.M. Writing was led by B.E.L. and L.T.B. with input and edits from all authors.

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Correspondence and requests for materials should be addressed to Beverly E. Law.

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