COLLINS Eleni * ODF

From: Brenna Bell <brenna@350pdx.org>
Sent: Friday, January 17, 2025 11:39 AM
To: FORESTRY Boardof * ODF
Subject: Testimony follow-up for last week's meeting
Attachments: Board of Forestry Follow-up comments 1.25.pdf

Follow Up Flag: Follow up
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Hi Eleni,
Thanks for getting these attached comments to the Board Members and in the record!

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Brenna Bell (she/her)
Forest Climate Manager, 350PDX
brenna@350pdx.org

"You cannot buy the Revolution. You cannot make the Revolution. You can only be the Revolution. It is in your spirit, or it is nowhere." *- Ursula K. LeGuin, The Dispossessed*

Oregon Board of Forestry
Oregon Department of Forestry
2600 State Street
Salem, Oregon 97310

submitted via email: boardofforestry@oregon.gov

17 January, 2024

Re: Jan. 9, 2025 meeting, agenda item 14: CCCP implementation update

Dear Chair Kelly and Members of the Board,

Two years ago, 14 organizations submitted comments calling attention to the lack of specificity in ODF's 2022-24 work plans regarding implementation of the Climate Change & Carbon Plan (CCCP). I've included that letter at the end of this comment because it is still very relevant and none of the issues raised in that letter have been adequately addressed. ODF needs Work Plans, and those Work Plans need specificity about the CCCP.

At the last Board of Forestry meeting, several commenters raised concerns about ODF's lackluster implementation of the CCCP. I was hopeful that the scheduled presentation would provide specifics about progress on each of the Climate Smart Forestry Goals, for example:

- linking the "supporting actions" in the CCCP to the goals;
- establishing who in ODF is responsible for managing progress on each action or goal;
- sharing whether existing programs are sufficient to meet the goal or whether it requires future planning/funding;
- highlighting measures by which ODF is determining whether progress on the goals are being made, etc.

Rather than answering any of these questions, the staff presentation left me with the impression that the staff in charge may lack the project management skills needed for the task. With respect to ODF staff, I think there has been a real gap in leadership since Ryan Gordon left the agency and that you'd be wise to invest in staff with strong management and implementation skills.

I know that ODF recently received $1.5 million in Natural Climate Solutions funds which are earmarked for "Climate Smart Forestry". Please use some of that money to hire a dedicated project manager to implement the actions and goals of the CCCP. I really think that this is the only way to move this very stuck issue forward and have any reasonable amount of time to prepare for the incoming climate crisis.

My best,
Brenna Bell
Forest Climate Manager
350PDX

Oregon Board of Forestry
Oregon Department of Forestry
2600 State Street
Salem, Oregon 97310

submitted via email: boardofforestry@oregon.gov 24 January, 2022

Re: Jan. 5, 2022 meeting, agenda item 4: ODF Work Plans

Dear Chair Kelly and Members of the Board,

In November 2021, you unanimously adopted a Climate Change & Carbon Plan (CCCP) for Oregon's forests. The CCCP lays out a framework to implement much needed changes that would ensure Oregon's forests provide a full range of social, economic and environmental benefits to the people of Oregon. This plan rightly recognizes that, with respect to the state's public forest lands, responsible climate action is not just consistent with achieving greatest permanent value to the people of Oregon, but fundamental to it. And as to Oregon's forested landscape as a whole, the Plan represents a crucial first step in Oregon becoming a leader in climate-smart forestry, and creating a model for how to best use forests as a critical natural climate solution.

Adopting the CCCP was just the first step. The work now is to ensure the Plan's goals are well represented both in the Oregon Department of Forestry's 2022-24 work plans and budget. Since the Work Plans lay out the priorities for the department for the next two year, it must provide a road map for meeting the climate crisis that reflects the importance of this issue and the short timeline that we all face. Unfortunately, the draft work plan shared in the January 5th Board of Forestry meeting does not provide either urgency or specificity for implementing the CCCP. The undersigned organizations request that the final draft of the Climate Change and Forest Carbon work plan be significantly revised to include a framework for implementing the CCCP, including specific goals, actions and timelines.

To begin, the Overview for the Climate Change and Forest Carbon work plan focuses almost exclusively on the impacts of wildland fire. While our warming and drying climate is extending the fire season and impacting forests and communities across Oregon, the Overview should be far broader and reflect the principles of the CCCP. These principles recognize that:

- Climate change is a serious threat. We have less than a decade to alter behaviors if we want to avoid catastrophic impacts. We must be innovative, creative, and proactive in working towards solutions, not simply react to the results of climate change.
- Black, Indigenous, and People of Color (BIPOC) communities have been and continue to be some of the most climate-impacted communities. Forest policies will be shaped through the lens of social justice and equity. Actions will prioritize benefits to historically and currently underserved communities as they adapt to a changing climate.
- Oregon's forest sector offers opportunities for significant sequestration and storage both in the forest and in harvested wood products. As well as opportunities to promote clean

water and air, while preserving forest resilience in the form of flood control, biodiversity, thermal refugia, etc.
- As changing climates affect forests, incorporation of the best available science and practices will be key to adaptive management and planning across ownership type, size, and goals.

Incorporating these principles into the Overview for the Climate Change and Forest Carbon work plan will provide more context and ensure that ODF can assess its proposed work against these principles to ensure that all aspects of the issue are adequately addressed.

In its summary of work to date, the work plan addresses the CCCP and notes that "[i]ncorporation of the CCCP will take place in processes like the Forest Management Plan, Implementation Plans, and also provide a guiding path for the Forestry Program for Oregon revision (in the Overarching Issues workplan)." While we appreciate that tenets of the CCCP are being incorporated into the FMP and subsequent implementation plans, state forest management was only one section of the CCCP - its goals are far more comprehensive across jurisdictions. Also, upon cross-referencing with the Overarching Issues workplan, we note that the CCCP is only mentioned in the context of how it slowed down revising the Forestry Plan for Oregon (FPFO), accompanied by an implicit suggestion that the new FPFO will incorporate the CCCP. These mechanisms alone do not match either the scope or urgency laid out in the CCCP.

Next, the section titled Topic A: CCCP Tracking provides little information about how the CCCP will actually be implemented *or* tracked. We urge the agency to provide more specific information to accompany the first sentence, "With the approval of the Climate Change and Carbon Plan . . . various divisions, and programs have begun working on the implementation of the goals and supporting actions." While we don't doubt this is happening, we have scoured ODF's work plans and find little across the various divisions and programs that explains how it is being implemented. It would deeply benefit the public's ability to track implementation of the CCCP if ODF includes a more specific list connecting the goals and actions outlined in the CCCP with the divisions and programs tasked with achieving those goals.

For example, at the end of the CCCP there is a list of "Future Work Needs" including tasks such as "Request Department of Justice assessment of Measure 49 impact on implementation of climate goals"; "Integrate climate change in the complete and coordinated fire response strategy"; and "Align budget requests and priorities to cope with a changing climate." There are also goals like "establishing a grant program of $2 million per year to empower local communities to invest in urban canopy that meets their needs." These are but a few of the specific actions and goals that we do not see reflected in ODF's work plans.

Accomplishing these future work needs and goals will only be done when specific staff or departments are tasked with doing so. We acknowledge that the agency is in the midst of both a staff transition and shortage, and that it may be challenging to provide specificity as to who will be doing what, when. We also acknowledge that ODF needs more funding to implement these plans. However, given that this is a two-year work plan, we encourage ODF to include work that doesn't yet have funding or staff but is likely to fall within the life of the work plan.

Adequately addressing the climate crisis requires bold action now. Adopting the CCCP was an important step, but providing a clear, actionable implementation plan is necessary to ensure ODF acts with the urgency this crisis demands.

We appreciate your consideration of these comments, and all the work you do on behalf of Oregon's forests.

Sincerely,

Brenna Bell
Forest Climate Manager
350PDX

Nick Cady
Staff Attorney
Cascadia Wildlands

Joseph Youren
Audubon Society of Lincoln City &
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Forest Climate
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Alan Journet Ph.D.
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Southern Oregon Climate Action Now

Rand Schenck
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Ashley Short
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Tualatin Riverkeepers

Noah Greenwald
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Andrew Collins-Anderson
Co-Director
Coast Range Association

Julia DeGraw
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Angus McLean
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Pacific Forest Trust

Catherine Thomasson, MD
Environmental Caucus
Democratic Party of Oregon

From: Carol Valentine <cvalentinemusic@gmail.com>
Sent: Thursday, January 09, 2025 11:20 AM
To: FORESTRY Boardof * ODF
Cc: Forest team Oregon SC; Oregon Conservation Committee
Subject: OR Sierra Club Public Comment 1-9-25
Attachments: OR Sierra Club BOF Comment 1-9-25.pdf (CV).pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Testimony-Board-Mtg.

Greetings Board members,

Please see attached testimony regarding implementation of the Climate Change and Carbon Plan from the Oregon Chapter Sierra Club for the January 9 Board of Forestry record.

Thank you,

Carol Valentine

Carol Valentine (she/her)
Forest Team Coordinator
Oregon Chapter Sierra Club
cvalentinemusic@gmail.com

Even a wounded world is feeding us. Even a wounded world holds us, giving us moments of wonder and joy. I choose joy over despair. Not because I have my head in the sand, but because joy is what the earth gives me daily and I must return the gift.
— Robin Wall Kimmerer

SIERRA CLUB
OREGON CHAPTER

January 9. 2025 Public Comment:

Chair Kelly, State Forester Mukumoto, and members of the Board,

For the record, my name is Carol Valentine. I am commenting on behalf of the Oregon Chapter Sierra Club regarding implementation of the Climate Change and Carbon Plan. We appreciate the work of ODF and the Board in creating the plan 3 years ago and look forward to today's update on implementation. We request that updates on ODF's progress in achieving the recommendations in the CCCP become a regular occurrence.

We ask the Board to adopt targets that are SMART—meaning specific, measurable, achievable, relevant, and time-bound—for contributing to the additional sequestration goals identified by the Oregon Climate Action Commission: 5 million metric tons of carbon dioxide equivalent by 2030 and an additional 9.5 million metric tons of carbon dioxide equivalent annually by 2050.

Overall, management must aim to increase the percentage of older trees in our state forests, as they store the most carbon. They are also the most fire resistant and provide much needed habitat for the species that depend on mature forests.

While the first priority for managing the Habitat Conservation Areas and Riparian Conservation Areas is to benefit endangered species, the next highest priority should be to manage conservation areas as carbon reserves. As part of implementing the CCCP, management plans should retain mature stands 80 years or older adjacent to HCA boundaries as carbon banks. These would also function as "stay ahead" reserves for the HCP, helping the HCP be successful over time.

Thank you,
Carol Valentine, Forest Team Coordinator
Oregon Chapter Sierra Club

COLLINS Eleni * ODF

From: Casey Kulla <ck@oregonwild.org>
Sent: Wednesday, January 08, 2025 10:00 AM
To: FORESTRY Boardof * ODF
Subject: Public Comment 1/8/25
Attachments: science.177.4044.139.pdf; science.adl5889.pdf; science.Balch et al. adk5737.pdf

Follow Up Flag: Follow up
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Categories: Testimony-Board-Mtg.

Board of Forestry public comment

Good morning, Chair, members of the board, State Forester Mukumoto, and staff. For the record, my name is Casey Kulla and I work for Oregon Wild.

Today, in light of the disastrous urban wildfires in Los Angeles (PAUSE), I'd like to thank the folks at ODF involved in the wildfire funding workgroup. Thank you to Ryan Miller, Kyle Williams, Derrick Wheeler, Gina Miner, Nathan Beckman, Chair Kelly, Cal, and I'm sure I'm missing ODF folks.

Regarding your climate change and carbon plan and how it is related to wildfire funding and human safety: both the latest and 50 yr old science demonstrate that we have to acknowledge a new fire reality and pivot.

Jones et al 2024 observe: "In pyromes with a history of aggressive wildfire suppression, shifting focus and funds from active fire suppression to managed, ecologically beneficial fires may prevent C sink-to-source conversion." They conclude: "Irrespective of mitigation and adaptation measures, cutting anthropogenic emissions is central to securing resilient forests for the future."

Observing aggressive fire suppression, Dodge in 1972 says total fire exclusion in forests is both impossible to achieve and ecologically undesirable. He demonstrates the value of prescribed fire and allowing large fires to do the work of reducing fuel hazards. Concluding, he says: "More men and more fire trucks will not solve the problem of bigger and more damaging wildfires, although they may delay the ultimate results."

Balch et al 2024 concludes that fast moving wildfires are the most destructive fires. These are fires that burn homes and threaten people, and they don't respond to traditional suppression strategies.

So, what can policy makers like yourselves do?
Accelerate carbon sequestration in wet western Oregon forests.
Accelerate prescribed burning in drier forests.
Invest in community risk reduction.
Move to managing some fires.
And grow more beavers. Thank you!

See attached Balch et al, Jones et al, and Dodge papers to continue our education on fire management.

CASEY KULLA
State Forest Policy Coordinator
he/him/his
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Let Nature Live. Let Nature Last.
Celebrating 50 years of protecting Oregon's wildlands, wildlife, and waters.

Forest Fuel Accumulation—A Growing Problem

Marvin Dodge

Fire fighters in the western forests are doing an effective job. They have not yet reached the goal of total exclusion of fire, but over 95 percent of the wild fires are extinguished while small. The 3 to 5 percent that get out of control cause 95 percent of the damage.

This small percentage does tremendous damage. The 1967 fire season in the Pacific Northwest and Northern Rockies was a blow to the national economy as well as to the local timber and recreation industries. The year 1970 saw a repeat of huge fires in eastern Washington during the summer. Southern California was declared a disaster area by President Nixon. The final toll for California was 14 lives lost, 800 homes and buildings destroyed, and 242,000 hectares (600,000 acres) of timber and watershed cover burned.

More disastrous fires may be expected in future years. A major factor contributing to this prediction is the accumulation of dead fuels taking place in the wildland areas of the western United States. The fire control agencies may be making the situation worse. William E. Towell, chairman of a fire study group for the American Forestry Association, said (*1*), ". . . a fire control agency's worst enemy may be its own efficiency. The longer forests go without burning, the greater the fuel accumulation and the greater the hazard."

Forest Fuels

The fuels that burn in a forest fire are generally separated into two classes, living fuels and dead fuels. The living fuels, consisting of leaves, twigs, and stems of growing plants, are difficult to ignite and do not burn readily by themselves. When the moisture content of living plants is reduced by drought and when they are further heated and dried by a fire in dead fuels beneath them, they can burn, sometimes very intensely.

The real problem is dead material, consisting of fallen leaves and needles, dead twigs and branches, dead stems either standing or fallen, and dead grass and weeds. Fires start easily in dry, dead fuels and spread readily. The fuels that contribute most to fire intensity and rate of spread are those about 1 centimeter in diameter and smaller, plus the outer few millimeters of larger branches and logs. Larger fuels do not contribute to intensity or rate of spread since they burn after the main fire front has passed. These larger fuels do cause the fire to persist and are difficult to extinguish. They may also provide a source of burning embers for further fire spread.

A general formula for fire intensity (I) was developed by Byram (*2*):

$$I = HWR$$

where H is the heat or energy value of the fuel, W is the weight of fuel per unit area, and R is the rate of spread. Thus, increasing the fuel loading increases the intensity of the fire. However, not all the relations for free-burning fires have been worked out. According to Hodgson (*3*), Australian fire researchers found that doubling the amount of fine fuels (such as leaves, twigs, and long strips of bark) also doubled the rate of spread. This produces a fourfold increase in intensity. This relationship has not been verified by experiments in the United States, nor have the effects of large volumes been adequately explored.

Conditions for Fuel Accumulation

All plants produce yearly increments of dead material. Annuals leave the whole plant body as fuel at the end of the growing season. Perennials shed leaves or needles and dead twigs every year, some species throughout the year, and others seasonally. At greater intervals the perennials contribute dead branches that have been shaded out by subsequent growth and, eventually, the stems or trunks of the dead plants that have completed their life cycles.

The normal annual increment of dead fuel may be increased tremendously by events that kill a sizable proportion of the plants growing in the area. Insect and disease epidemics, blowdown during storms, timber harvesting, and wildfire all contribute great quantities of dead material.

Very few studies have been made of the annual accumulation of litter. Accumulation rates of 1.1 to 3.2 tons per hectare were found in the chaparral of southern California by Kittredge (*4*). Studies by Biswell and his colleagues (*5*) of several species in the central Sierra Nevada showed that 2.2 to 6.9 tons of litter per hectare are contributed each year to the forest floor.

Climate plays an important part in the accumulation of dead fuels. Both Kittredge (*4*) and Olson (*6*) have pointed out that in warm, moist climates, which provide an optimum environment for decomposition, there is little or no litter. Where conditions are less favorable for decomposition, as in a cool, moist climate, there is a greater accumulation of dead materials. A climatic pattern of warm, dry summers and wet, cool or cold winters leads to maximum accumulations of dead fuels or stored energy that may be released by wildfires. Thus we should expect the greatest potential for disastrous wildfires in the western United States.

There have been few measurements or estimates of the quantities of dead fuel under growing forests or brush fields. Weaver, discussing the ecology of the ponderosa pine (*Pinus ponderosa*), pointed out the great increase in fire hazard which results from fuel accumulation under almost complete fire protection (*7*). He found fuel quantities large enough to make control nearly impossible if a fire should start during critical weather conditions (*8*). In studies of the giant sequoia (*Sequoiadendron giganteum*) groves as much as 56 to 94 tons of dead fuel per hectare were found (*9*). Southern California has a reputation for devastating forest and brush fires, yet only two studies have been made of the amount of material fueling these fires (*10*).

Although the figures are sparse for California, there is an even greater lack

The author is a state forest ranger with the forestry division of the California Department of Conservation, Sacramento 95814.

of quantitative data for fuel loadings in the Northwest and the Rockies. The only published data are those obtained in a brief study of a small area in northern Idaho by Anderson (*11*). In 1967, during an extensive air and ground survey of forest conditions on a transect from western Montana across northern Idaho into eastern Washington, I found that nearly half the area has loadings of dead fuel ranging from 90 to 135 tons per hectare. And many sites have up to 225 tons of dead fuel per hectare beneath the overmature standing timber.

Critical fire weather, long periods of drought culminating in a few days of very low humidities and strong winds, only occurs on an average of once in 10 or 15 years in the Pacific Northwest and Northern Rockies. But when a fire does start in these conditions in an area with large quantities of dead fuels, it will be so intense that little or nothing can survive.

Fire History

Forest fire was a regular phenomenon in the western United States before the white man arrived. Show and Kotok (*12*), in one of the earlier studies of fire chronology for California, found that fires have occurred at intervals of about 8 years since 1685, which was as far back as they could reliably date the trees studied. They stated that forests persisted in spite of the numerous fires, which indicates that most were light surface fires. The pine forests of California, Oregon, and eastern Washington (*13*) and of the Southwest (*14*) all have long histories of fire. In the Southwest, areas of pine forest with periodic fires were still open and parklike, but well stocked with young pines, in 1951 (*14*).

Great arguments have raged over whether Indians set fires or whether fires were all started by lightning. Readers may wish to refer to articles by Burcham (*15*) and Stewart (*16*) for examples of opposing views. However interesting this history may be, it has little bearing on today's problems. The management practices (or lack thereof) of a hunter-gatherer culture were determined by conditions entirely different from those prevalent now. Today's management decisions must be made with regard to present economic and social conditions and must be based on sound principles and definite goals, not nostalgic recollections of a rather vague historic past.

Conditions changed drastically with the arrival of white men in the West. Extensive forest areas were cut for building materials for new towns and farms, mine timbers, and fuel wood. The western forests also supplied wood for the continued economic growth of the East and Midwest. Logging left great quantities of slash—treetops, limbs, and waste—on the ground. The opening of the crown canopy permitted greater insolation and drying of the increased amounts of dead fuel on the ground, and the removal of obstructing trees also produced higher wind velocities at ground level. The result of these more severe conditions was a series of devastating fires over the years. According to Davis, who compiled a list of the large forest fires in the past (*17*), "It is a significant fact that every one of the fires listed started in slash or other debris resulting from logging and land clearing and gained initial momentum from such fuels."

The destruction wrought by these early logging-slash fires undoubtedly created the sentiment and reasoning that led to the policy of total fire protection. While this concept of complete exclusion of fire was probably the only practical solution at the time, it has created other problems, some of which are just beginning to be recognized now. As discussed above, dead fuels have accumulated and present a serious hazard in many areas. Fire exclusion has also altered the ecological relationships of the forests, changing drastically the composition and growing conditions of many timber stands (*18*).

Fire has been essential for perpetuating valuable species (*19*). For example, Haig stated that Douglas fir (*Pseudotsuga menziesii*), western white pine (*Pinus monticola*), and lodgepole pine (*P. contorta*) have been maintained in more or less pure form by fire (*20*). He further observed that foresters have been reluctant to accept the idea that fire may aid regeneration. Observations of giant sequoias have indicated that reproduction occurs primarily on burns or mechanically disturbed areas (*21*).

Since reproduction occurs on mechanically disturbed sites as well as on burned areas, we must consider fire as only one means of securing a mineral seedbed. However, many other ecological considerations have been studied very little. Hartesveldt *et al.* (*21*) referred to the occurrence of pathogenic fungi in soil and the beneficial effect of fire in sterilizing soil. Baker (*22*) suggested that leaving large quantities of slash and debris may produce an unfavorable carbon/nitrogen ratio.

Greatly increased growth rates in fire-thinned patches of pine compared to unthinned stands were reported by Weaver (*8*). He suggested that the elimination of fire-thinning of sapling and pole-sized trees has led to greatly increased competition, subsequently weakening the trees and making them more vulnerable to insect attack (*7, 14*). Stocking rates, giving the optimum number of trees per hectare for best vigor and growth, support his views (Table 1). In addition, corrective measures, such as deliberate thinning, may increase the fire hazard. It was found that slash produced in thinning ponderosa pine in the Northwest greatly increases fire intensities and also resistance to fire-control efforts since the jackstrawed stems are difficult to clear for fire lines (*23*).

Present Approaches

Many fire control men recognize that a problem of fuel accumulation exists. Brown (*24*) stated that "The amount of fuel that is allowed to accumulate and its continuity are recognized by fire control men everywhere as fundamental in determining the cost of effective fire control and in fixing the losses that are bound to occur over a period of years." In the wildland research plan for California (*25*) it was pointed out that the stockpiles of dead fuels continue to accumulate, and Edward P. Cliff, then chief of the Forest Service, commented that (*26*) "Disposal of logging slash and reduction of fuel build-up through prescribed burning or other means constitute special challenges."

Even though the problem has been recognized, little has been done to measure its magnitude or extent. Proposed solutions have taken a number of directions. Efforts to find efficient chemical or biological digesters of dead fuels have not been successful. Mechanical chipping and shredding is quite expensive, with estimated costs running from \$148 to \$222 per hectare when prison labor is used. Efforts have been made to crush and chop slash and brush with heavy mechanical equipment (*27*). No cost figures have been published, but one administrative study by the California Division of Forestry showed costs of \$73 to \$99 per hectare.

The old concept of firebreaks permanently cleared on ridgetops has been extended to fuel breaks. These are strips

30 to 91 meters or more in width where the heavy fuels have been removed to break up large expanses of brush or timber (28). They are often seeded to grass to minimize erosion, with only a narrow strip in the middle cleared to mineral soil. The cost of clearing and maintaining them runs from $3500 to $5000 per kilometer. And fuel breaks do not eliminate the problem of fuel accumulation, they merely divide it up.

Another possible solution, prescribed burning, has been a subject of tremendous controversy. Weaver has often proposed the use of fire both as an ecological tool and for hazard reduction (7, 8, 14), and Biswell (29) has pointed out that the removal of dead fuel by prescribed burning reduces the damage from wildfire. These proposals have often been greeted by an emotional reaction and the view that all fires are raging monsters that destroy everything. The critics fail to recognize the differences between high-intensity wildfires that do destroy everything and low-intensity fires that may cause little or no damage.

Several studies of logging-slash flammability have been made, and there is a considerable amount of prescribed burning on clear-cut blocks where no vegetation remains (19, 30). However, these are all high-intensity fires, and less attention has been given to fuel accumulations outside of logging areas or to the use of low-intensity fires.

In two studies, low-intensity fires have been used in timber areas. Gordon's study in dense, stagnated stands of ponderosa pine saplings and poles is difficult to evaluate as few data are given on the sizes or number of trees (31). The photographs included in the report seem to indicate that the stands were extremely thick and that burning thinned the suppressed trees effectively. The costs on small plots (about 0.4 hectare) ran from $51.91 to $69.72. Schimke and Green (32) discussed the use of prescribed fire for maintaining fuel breaks in the central Sierra Nevada. They gave recommendations for weather conditions suitable for maintaining low-intensity fires and reported average costs of $10.45 per hectare.

Attempts by the National Park Service to restore natural ecosystems are encouraging. Houston (33) has reported on efforts with prescribed burning and natural fires in Sequoia and Kings Canyon national parks. Studies are being conducted in Yosemite National Park to obtain definite data on the effects of fire by using different weather and fuel conditions according to Schimke and Green's prescriptions (32). No results of these studies have been published to date, but my examination of several treated areas showed effective thinning and hazard reduction.

Table 1. Density of trees for full stocking (37). Diameter, average diameter at breast height; *N*, number of trees; ha, hectare.

Diameter (cm)	Density (*N*/ha)	
	Ponderosa pine	Douglas fir
10.2	4700	3110
15.2	2470	1865
20.3	1480	1300
25.4	990	956
50.8	247	296
76.2	106	173

High-intensity fires have been used widely in brush areas for range conversion and hazard reduction. Since the passage of enabling legislation, nearly 800,000 hectares have been burned by private property owners in California (34). This activity is decreasing, probably because most of the areas in which it is economically feasible have been treated and because of the increasing financial liability associated with high-intensity fires. An economic study of controlled brush burning showed steadily decreasing costs with increasing size of the burn up to 178 hectares, where costs totaled $1.48 per hectare. Above that size, costs again rose slightly (35). These costs for high-intensity burns contrast sharply with those given for small plots and illustrate clearly the differences in scale. On a large scale, low-intensity fires would be considerably easier and cheaper to manage.

It must be recognized that there are many areas where high volumes of fuel would cause severe damage with any attempt at burning. However, little valid work has been done on the effects of low-intensity fires in the West. There are possible damages and disadvantages in the use of fire, but we may be forced to accept them as the premiums due for insurance for the whole forest. Evidence that a program of prescribed burning is compatible with modern economic and social objectives is given in Australia. Heavy losses in a series of disastrous fires prompted a study of management objectives. Their attempts at total fire exclusion had made changes in the nature of the forest and, while reducing the area of forest burned annually, had produced more severe and damaging bush fires (36). They concluded that complete fire protection is almost impossible to achieve and is undesirable ecologically. Hence, they have started a program of prescribed burning to reduce the fire hazard and restore the ecological conditions needed by the forest and wildlife.

Conclusions

Fire has been part of the western forests, probably for thousands of years. Apparently these frequent fires consumed much of the dead fuels and prevented large fuel buildups. Since fire protection agencies started their policy of total fire protection, dead fuels have gradually accumulated in many areas and represent a serious hazard. Studies and surveys should be started to obtain data on fuel volumes and distributions.

The large quantity of stored energy in accumulated fuels is released rapidly by fires, producing very high fire intensities. It is reasonable to predict that, where fuels are permitted to accumulate, fires will become more severe and more damaging and will be more difficult to control. More men and more fire trucks will not solve the problem of bigger and more damaging fires, although they may delay the ultimate results. The only big improvement possible in forest fire protection lies in the area of hazard reduction.

Intensified efforts to find economical and practical ways to reduce the fuel hazards are needed. The relatively neglected use of prescribed burning should be considered, particularly the use of low-intensity fires. Advantage should be taken of large wildfires that have reduced the fuel hazards, and vigorous efforts should be made to prevent future fuel accumulations.

References

1. W. E. Towell, *Amer. Forests* **75** (6), 12, 40 (1969).
2. G. M. Byram, in K. P. Davis, *Forest Fire: Control and Use* (McGraw-Hill, New York, 1959), pp. 61–89.
3. A. Hodgson, *J. Forest.* **66**, 601 (1968).
4. J. Kittredge, *Forest Influences* (McGraw-Hill, New York, 1948).
5. H. H. Biswell, R. P. Gibbens, H. Buchanan, *Calif. Agr.* **20** (9), 5 (1966); J. K. Agee and H. H. Biswell, *ibid.* **24** (6), 6 (1970).
6. J. S. Olson, *Ecology* **44**, 322 (1963).
7. H. Weaver, *J. Forest.* **41**, 7 (1939).
8. ———, *ibid.* **45**, 437 (1947).
9. H. H. Biswell, R. P. Gibbens, H. Buchanan, *Nat. Parks Mag.* **42** (No. 251), 16 (1968); J. K. Agee, thesis, University of California, Berkeley (1969).
10. Progress Report 5, Operation Firestop, California Division of Forestry and Cooperative Agencies (1955); L. R. Green, *U.S. Forest Serv. Res. Note PSW-216* (1970).
11. H. E. Anderson, *U.S. Forest Serv. Res. Pap. INT-56* (1968).
12. S. B. Show and E. I. Kotok, *U.S. Dep. Agr. Circ. 358* (1925).
13. W. W. Wagener, *J. Forest.* **59**, 739 (1961).

14. H. Weaver, *ibid.* **49**, 93 (1951).
15. L. T. Burcham, in *Proceedings of the Society of American Foresters*, San Francisco (1959), pp. 180–185.
16. O. C. Stewart, *Geogr. Rev.* **41**, 317 (1951); in *Man's Role in Changing the Face of the Earth*, W. L. Thomas, Ed. (Univ. of Chicago Press, Chicago, 1956), pp. 115–133.
17. K. P. Davis, *Forest Fire: Control and Use* (McGraw-Hill, New York, 1959).
18. M. Oberle, *Science* **165**, 568 (1969).
19. D. S. Olson and G. R. Fahnstock, *Univ. Idaho Forest Wildl. Range Exp. Sta. Bull. 1*, (1955).
20. I. T. Haig, *J. Forest.* **36**, 1045 (1938).
21. R. Hartesveldt, H. T. Harvey, H. S. Shellhammer, R. E. Stecker, *Science* **166**, 522 (1969).
22. F. S. Baker, in *Regional Silviculture of the United States*, J. S. Barrett, Ed. (Ronald, New York, 1962), pp. 460–502.
23. G. R. Fahnstock, *U.S. Forest Serv. Res. Pap. PNW-57* (1968); J. D. Dell and D. E. Franks, *Fire Control Notes* **32** (1), 4 (1971).
24. A. A. Brown, *J. Forest.* **45**, 342 (1947).
25. California Division of Forestry, "Wildland Research Plan for California" (California Division of Forestry, Sacramento, revised, 1969).
26. E. P. Cliff, *Amer. Forests* **75** (6), 20 (1969).
27. K. O. Wilson, *J. Forest.* **68**, 274 (1970).
28. U.S. Forest Service, "Progress Report on Fuel-Break Research" (U.S. Forest Service, Pacific Southwest Station, Berkeley, 1969).
29. H. H. Biswell, *Calif. Agr.* **13** (6), 5 (1959).
30. G. R. Fahnstock, *U.S. Forest Serv. Intermt. Forest Range Exp. Sta. Res. Pap. 58* (1960); E. R. De Silvia, *Proceedings of the Tall Timber Fire Ecology Conference*, Tallahassee, Florida (1965), pp. 221–330; R. W. Steel and W. R. Beaufait, *Univ. Mont. Mont. Forest Conserv. Exp. Sta. Bull. 36* (1969).
31. D. T. Gordon, *U.S. Forest Serv. Res. Pap. PSW-45* (1967).
32. H. E. Schimke and L. R. Green, "Prescribed Fire for Maintaining Fuel-Breaks in the Central Sierra Nevada" (U.S. Forest Service, Pacific Southwest Station, Berkeley, 1970).
33. D. B. Houston, *Science* **172**, 648 (1971).
34. California Division of Forestry, "Brushland Range Improvement Annual Report" (California Division of Forestry, Sacramento, 1969).
35. A. W. Sampson and L. T. Burcham, "Costs and Returns of Controlled Brush Burning for Range Improvement in Northern California" (California Division of Forestry, Sacramento, 1954).
36. R. G. Vines, *Aust. Sci. Teach. J.* (November 1968), reprint.
37. G. A. Craig and W. P. Maguire, *The California Pine Region Handbook* (California Division of Forestry, Sacramento, 1949).

The Politics of Projection: A Critique of Cartter's Analysis

Ted R. Vaughan and Gideon Sjoberg

In a series of articles from 1965 to 1971 (*1*, *2*), Allan M. Cartter has advanced the thesis that American graduate education is oriented toward the systematic overproduction of Ph.D.'s. This overproduction is, he asserts, already evident and, unless policies are altered drastically, is destined to become an acute problem in the early 1980's.

Cartter's thesis, phrased in a progressive tone, has gained widespread acceptance because it is supported by certain demographic data and by the difficulties that some recent recipients of the doctorate have experienced in securing employment. But Cartter's argument can be faulted on a number of critical points. He ignores fundamental social changes already under way within American society, changes that are likely to erode the very bases of his projections. Moreover, his implicit assumptions about the future relations among politics, the economy, and education are open to serious question. Our intention is to point out the serious weaknesses in Cartter's analysis and to demonstrate that it represents a highly unreliable point of departure for policy-making in graduate education.

The Essentials of Cartter's Argument

The serious imbalance between supply and demand of Ph.D.'s is, according to Cartter, occasioned by the continuation of outdated expansionist policies, particularly on the part of state planning agencies, which have overlooked the markedly changed conditions that will surround higher education in the 1970's and 1980's. The basic pattern, one that has already begun to undermine present policy, is a decrease in the rate of growth of the college-age population (18 to 21) in the decade between 1968 and 1978 and an absolute decline in its numbers during the decade to follow. Thus, Cartter concludes, at the very time that the need for new faculty in higher education is declining, the number of Ph.D. degrees granted is continuing to increase. This trend will lead to a situation wherein "only about one doctorate in four will find suitable academic employment, and in the 1980's it could be less than one in ten" (*1*, p. 136).

Cartter contends that neither higher rates of college enrollment nor maximum hiring levels will correct the imbalance. Although he does not believe that either of these developments is likely, he concludes emphatically that (*1*, p. 137):

> Even if all junior colleges were converted to 4-year colleges, every high school graduate went to college, and every new college teacher hired in the future possessed the Ph.D., by 1980 a smaller percentage of doctoral degree recipients would be likely to find academic positions than has been true for the preceding 25 years.

Furthermore, the nonacademic employment sector will be incapable of absorbing the surplus of Ph.D.'s who will graduate in the years to come.

In light of his pessimistic conclusions, Cartter suggests certain means for dealing with the oversupply of Ph.D.'s. Professional associations should establish manpower study commissions with a view toward monitoring the production of doctorates within the disciplines related to their professions; colleges and universities should consider both restricting graduate programs and opening up more positions for younger Ph.D.'s through earlier retirement of faculty and changed tenure procedures; and, what is perhaps most important, the federal government should assure a certain level of support for "national universities" or for selected departments within various disciplines. These national universities would become the major centers for graduate education.

The Impact of Cartter's Argument

Although Cartter expresses concern that his argument will be ignored or its policy implications deferred, an accumulating body of evidence suggests that Cartter's views have already begun to inform policy considerations. Cer-

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RESEARCH ARTICLE SUMMARY

FOREST FIRES

Global rise in forest fire emissions linked to climate change in the extratropics

Matthew W. Jones*, Sander Veraverbeke, Niels Andela, Stefan H. Doerr, Crystal Kolden, Guilherme Mataveli, M. Lucrecia Pettinari, Corinne Le Quéré, Thais M. Rosan, Guido R. van der Werf, Dave van Wees, John T. Abatzoglou

INTRODUCTION: Forest fires are a natural disturbance mechanism made more likely by climate change, with major impacts on global forest ecosystems and carbon (C) storage. Recent trends show a worrying increase in forest fire activity, particularly in extratropical regions. This study aims to disentangle the factors driving the recent increases in fire activity by analyzing global forest fire extent and emissions and their relationship with climatic, human, and vegetation controls. Using machine learning, we grouped global forest ecoregions into 12 distinct pyromes in which forest fire extent depends on similar sets of controls.

RATIONALE: Understanding the drivers of fires in distinct pyromes is essential for developing targeted strategies to predict and manage fire risks. By grouping forest ecoregions into pyromes with distinct fire controls, we aimed to better understand the regional variations in fire dynamics and their sensitivity to climate change. This approach allows us to isolate the effects of climate change from other influencing factors such as land use and vegetation productivity.

RESULTS: Our analysis revealed that extratropical forest fire emissions have increased substantially under climate change. Fire emissions in one extratropical pyrome spanning boreal forests in Eurasia and North America nearly tripled between 2001 and 2023. This increase was linked to a rise in fire-favorable weather conditions, reduced soil moisture, and increased vegetation productivity. By contrast, tropical pyromes showed a decline in fire emissions linked to reduced deforestation fires in moist tropical forests and increased fragmentation of dry tropical forests with agriculture and other land uses. Overall, forest fire C emissions increased by 60% globally during the study period, with the most substantial contributions coming from extratropical regions. The increase in extratropical fire activity highlights the strong influence of climatic factors compared with human activities, which play a more dominant role in tropical regions. The increases in forest fire C emissions were explained both by changes in fire extent and by changes in fire severity (measured in terms of the C emitted per unit area burned by fire). In the extratropical forest pyromes, we observed major increases in fire severity alongside expansion of areas affected by fire. This finding shows that the intensity and severity of fires is increasing in extratropical forests, which is consistent with fires affecting drier, more flammable stocks of vegetation fuels as the climate warms and as droughts become more frequent.

CONCLUSION: The steep trend toward greater extratropical forest fire emissions is a warning of the growing vulnerability of forest C stocks to climate change. This poses a major challenge for global targets to tackle climate change, with fire reducing the capacity of forests to act as C sinks. Effective forest management and policies aimed at reducing greenhouse gas emissions are essential to mitigate these risks. Our study underscores the importance of considering regional distinctions in the controls on fire when developing strategies to manage fire and protect forest ecosystems. Proactive measures such as monitoring changes in vegetation and productivity can guide the prioritization of areas for forest management in the extratropics. In tropical pyromes, reducing ignitions during extreme fire-favorable weather and preventing forest fragmentation should protect forests and enhance C retention. In regions with substantial fire suppression history, shifting focus to managed, ecologically beneficial fires may prevent C sink-to-source conversion. Addressing the primary causes of climate change, particularly fossil fuel emissions, is central to minimizing future risks of forest fires globally and securing resilient forests for the future. In addition, our work supports growing calls for more comprehensive reporting of forest fire emissions to the United Nations as part of national reporting of anthropogenic C fluxes. The present norm of counting forest fire emissions fluxes as natural, on both managed and unmanaged land, is increasingly at odds with the observed growth in fire emission fluxes tied to anthropogenic climate change. This contributes to emerging gaps between the anthropogenic C budgets that are officially reported to the United Nations and the budgets constructed based on models and observations of terrestrial C stocks or atmospheric concentrations of CO_2. Finally, we highlight the potential for major overestimation of C storage (and therefore C credits) by reafforestation schemes in extratropical forests if the growing risk of fire disturbance is not appropriately factored into accreditation protocols. ■

PHOTO: STEFAN DOERR

Wildfire engulfs a boreal forest stand in Canada, 2016. During the historic fire season of 2023, nine times more C was emitted by fires in Canadian boreal forest than in recent decades.

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RESEARCH ARTICLE

FOREST FIRES

Global rise in forest fire emissions linked to climate change in the extratropics

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Climate change increases fire-favorable weather in forests, but fire trends are also affected by multiple other controlling factors that are difficult to untangle. We use machine learning to systematically group forest ecoregions into 12 global forest pyromes, with each showing distinct sensitivities to climatic, human, and vegetation controls. This delineation revealed that rapidly increasing forest fire emissions in extratropical pyromes, linked to climate change, offset declining emissions in tropical pyromes during 2001 to 2023. Annual emissions tripled in one extratropical pyrome due to increases in fire-favorable weather, compounded by increased forest cover and productivity. This contributed to a 60% increase in forest fire carbon emissions from forest ecoregions globally. Our results highlight the increasing vulnerability of forests and their carbon stocks to fire disturbance under climate change.

Fire is a natural ecosystem disturbance that has shaped the global distribution of Earth's forests and controlled carbon (C) storage in vegetation and soils over geological time (*1*–*3*). Nonetheless, anthropogenic climate change has contributed to an increase in fire-favorable weather conditions globally (*4*–*7*) and these enhanced risks have translated into increased burned area (BA) and fire C emissions in some forested regions during the past two decades or longer (*6*–*12*). Expanding land use or historic fire management policies have variably interacted with the effects of climate change to amplify or moderate forest fire activity and emissions (*13*, *14*). The increases in forest fire C emissions observed regionally contrast with declines in the global savannahs (*8*, *15*).

A series of highly anomalous episodes of extreme forest fire C emissions have recently punctuated longer-term trends (*11*, *16*–*19*). During the 2019 to 2020 bushfire season in Australia, the area burned by fires was more than double the previous record since 1930, and fire C emissions were also greater than in any other year since 2003 (*9*, *17*). In 2021, a new record was set for panboreal fire C emissions amidst a water deficit spanning both Eurasia and North America (*16*). In the 2023 fire season, fire C emissions from Canadian boreal forests were more than nine times the 2001 to 2022 average (*19*).

The increased occurrence of fire, particularly extreme fires, threatens the functioning and resilience of some forests as well as their ecosystem services, including C storage (*13*, *20*, *21*). The recovery of C stocks in vegetation and organic soils following forest fires can take decades to centuries, and so increases in annual fire C emissions and extreme emissions events lead to a lasting deficit of terrestrial C storage (*8*, *22*–*24*). Increased fire C emissions can thus reduce the capacity of global forests to absorb C from the atmosphere, posing a challenge for achieving climate targets. For example, increased fire activity in boreal North America alone is projected to result in net C losses equivalent to 0.3 to 3% of the remaining C budget necessary to limit global warming to 1.5°C (*25*).

Beyond their effects on C storage, extreme wildfires also cause major disruption or irreversible loss to society, including deaths, evacuations, reduced air quality, pressures on health care systems, and economic losses (*26*–*30*). Further, major declines in biodiversity have also been recorded in the wake of several extreme fire events and many of Earth's most threatened species are afflicted by an altered fire regime (*1*, *20*). Recent extreme wildfire seasons across the globe have demonstrated the power of extreme wildfires to affect both the environment and society.

One of the drivers of change in forest fire potential is anthropogenic climate change, which is causing more frequent and extreme periods of drought and fire-favorable weather, often referred to as fire weather (*4*, *6*, *31*). Increased hot and dry conditions create periods of low fuel moisture, promoting wildfire potential in ecosystems where ample stocks of fuels (vegetation biomass and organic soils) are available, notably in forests (*4*, *10*, *31*). Increased lightning frequency under climate change has also exacerbated the ignition of forest fires in some locations, particularly in ignition-limited forests of the high latitudes (*32*–*34*). Increased atmospheric instability has been linked to more erratic and extreme wildfire behavior that enhances fire spread and intensity and challenges the potential for firefighters to suppress fire (*35*, *36*). Several attribution studies have shown that climate change raised the likelihood of extreme fire weather conditions during a range of recent extreme wildfire seasons (*5*, *19*, *37*, *38*).

Alongside climatic factors, forest fire extent is controlled by various in situ human activities and by the ecological traits and productivity of vegetation (*6*, *39*–*42*). People influence patterns of forest fire in numerous ways, such as by using fire for forest clearing and land use (*43*), causing unwanted ignition (accidental or arson) (*44*), suppressing wildfires through firefighting (*45*), managing stocks of fuel on the landscape (*46*, *47*), increasing forest edge length through fragmentation (*48*, *49*), or inadvertently amplifying fuel stocks by excluding fire from forests where it is a central element of a functioning ecosystem (*14*, *50*). The composition of forest ecosystems with species that have developed fire-adapted evolutionary traits, such as canopy structure, self-pruning, and leaf waxiness, also influence fire dynamics (e.g., crowning potential) and rates of spread (*51*, *52*). In addition, the productivity of vegetation during the growing season influences fuel availability during subsequent dry seasons (*40*, *53*, *54*).

Although climatic, human, and vegetation factors all affect patterns of fire in forests, the prominence of each control varies regionally (*6*, *40*, *55*, *56*). The relationships between climate and fire are generally modulated by nonclimatic factors, and likewise non-climatic drivers of fire often depend on the episodes of fire-favorable weather. Hence, it has been challenging to identify the forest regions where fires are most sensitive to climate change or other facets of environmental change (*39*, *55*, *56*). To identify the world regions where responses to future climate change or other environmental stressors are comparatively strong or weak, further study of the temporal and spatial relationships between fire and a comprehensive set of fire controls is required.

We used the *k*-means clustering algorithm to group 414 forest ecoregions of the world (*57*) into 12 forest pyromes (Fig. 1), within which forest BA (*58*) shares a common set of relationships with climatic, vegetation, and human controls (Fig. 2 and figs. S1 and S2; also see Materials and methods). Having isolated the pyromes

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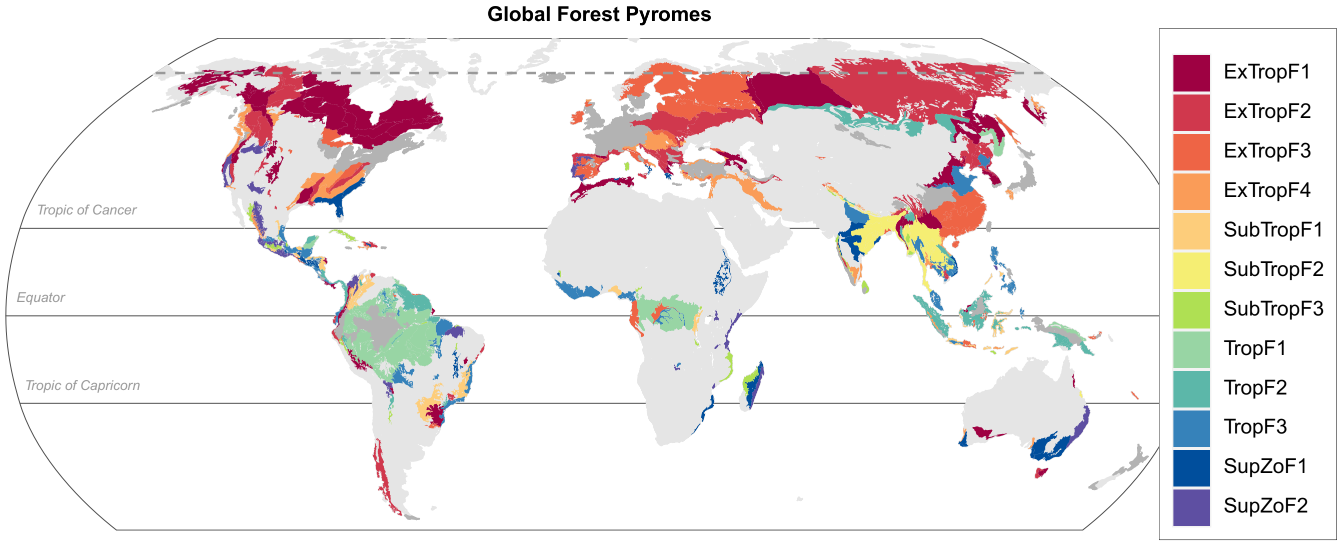

Pyrome	Associated Forest Biomes	Associated N−grams from Ecoregion Descriptions
ExTropF1	Boreal; Temperate broadleaf/mixed; Temperate coniferous; Mediterranean; (Sub)tropical moist broadleaf	taiga; mixed forests; forests canadian shield
ExTropF2	Temperate broadleaf/mixed; Temperate coniferous; Boreal; Mediterranean; (Sub)tropical dry broadleaf; (Sub)tropical moist broadleaf	mixed forests; mountains; taiga; dry forests; conifer; deciduous
ExTropF3	Temperate broadleaf/mixed; Temperate coniferous; Boreal; Mediterranean; (Sub)tropical moist broadleaf	broadleaf; conifer forests; deciduous forests; evergreen forests; mixed forests; moist; sclerophyllous; rain forests; swamp forests
ExTropF4	Temperate broadleaf/mixed; Temperate coniferous; Mediterranean; (Sub)tropical moist broadleaf; (Sub)tropical dry broadleaf	mixed forests; conifer; dry; montane; broadleaf forests; coastal; deciduous forests; forest steppe; himalayan; sclerophyllous
SubTropF1	(Sub)tropical dry broadleaf; (Sub)tropical moist broadleaf; (Sub)tropical coniferous	rain forests; dry forests; montane forests; lowland; pine
SubTropF2	(Sub)tropical dry broadleaf; (Sub)tropical moist broadleaf	moist deciduous forests; rain forests; subtropical; dry
SubTropF3	(Sub)tropical dry broadleaf; (Sub)tropical moist broadleaf; Temperate coniferous	dry forests; deciduous forests
TropF1	(Sub)tropical moist broadleaf	moist forests; congolian lowland forests
TropF2	(Sub)tropical moist broadleaf; (Sub)tropical dry broadleaf; Temperate broadleaf/mixed; Temperate coniferous	moist forests; lowland rain forests; montane rain forests; sumatran; swamp forests; conifer forests
TropF3	(Sub)tropical moist broadleaf; (Sub)tropical dry broadleaf	dry forests; moist forests; montane rain forests; coastal forests; swamp forests
SupZoF1	(Sub)tropical dry broadleaf; Mediterranean; (Sub)tropical coniferous; Temperate coniferous; (Sub)tropical moist broadleaf	coastal forest mosaic; dry deciduous forests; mixed forests; pine; woodlands
SupZoF2	(Sub)tropical dry broadleaf; (Sub)tropical coniferous; Temperate coniferous; Mediterranean; (Sub)tropical moist broadleaf	dry forests; montane; pine oak forests

Fig. 1. World map of the 12 forest pyromes and a summary of their tendencies to associate with biomes and ecoregion types. 414 forest ecoregions are attributed to one pyrome using *k*-means clustering, which identifies ecoregions sharing a similar set of correlations between burned area (BA) and 14 predictor variables (Fig. 2 and figs. S1 and S2). Gray areas are not included in the analysis, either because they are not within forest biomes (light gray) or because fire is extremely rare (the mean annual fraction of forest area burned by fire is below 0.01%; dark gray). Fig. S21 shows an alternative mapping of the pyromes for the ecoregions that were clustered most ambiguously. The table shows the most common biome associations for each pyrome and the most common text substrings (n-grams, up to three words) that appear in the ecoregion descriptions, based on the ecoregion descriptions in the Terrestrial Ecoregions of the World dataset (*57*).

with a distinctive strong sensitivity to climatic controls, we analyzed trends in annual forest BA (*58*) and fire C emissions (*59*) during the period 2001 to 2023 and evaluated their connection with trends in key climate variables.

We used a comprehensive set of fire controls to distinguish the pyromes. The climatic controls included fire weather (*4*, *60*, *61*), soil moisture (*62*), atmospheric instability (represented by the continuous Haines index) (*35*, *36*), and lightning frequency (*34*, *63*). The vegetation controls included potential fuel stocks related to land cover (*52*), vegetation productivity during the growing season (represented by the normalized difference vegetation index)

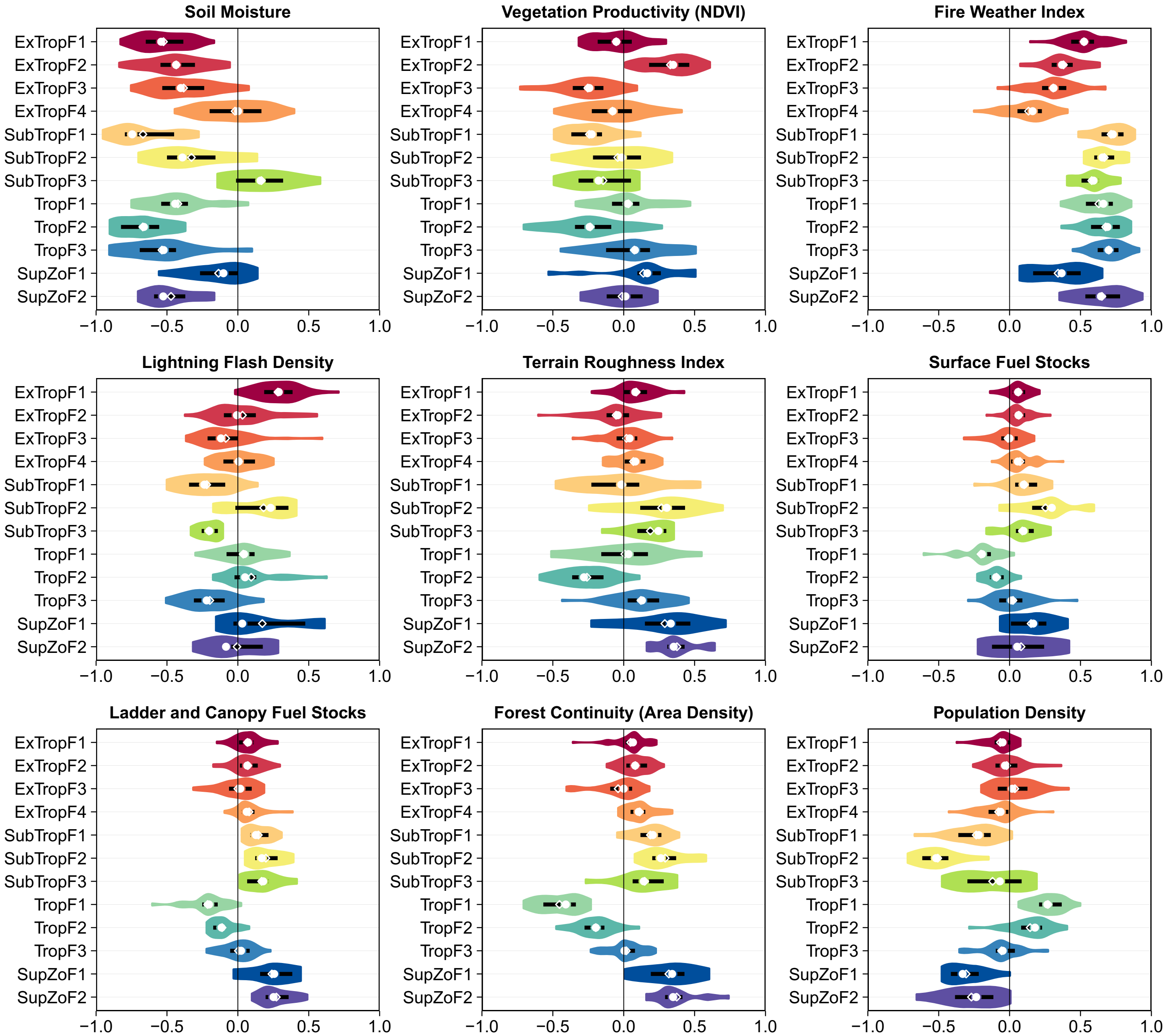

Fig. 2. Variation in the relationship between forest BA and nine predictors across the global forest pyromes. The violins plot the kernel density distribution of correlations values (Spearman's ρ) for each predictor among the constituent ecoregions of each pyrome. White dots mark the median correlation value for the ecoregions of a pyrome, black line ranges mark the interquartile range, and open diamonds mark the mean value. See Materials and methods for a description of all correlation analyses and the motivation for including each predictor. Distributions are shown for all predictor variables in fig. S1. Correlations are mapped for each forest ecoregion in fig. S2.

(*64*, *65*), and forest continuity (represented by forest area density) (*49*). The human controls included population density (*15*, *66*), cropland and pasture cover (*15*, *67*, *68*), and road density (*69*). Terrain roughness (*70*) is also included for its potential to affect fire behavior (*36*). These variables have each shown power to explain spatial or temporal variability in BA in at least some world regions (see Materials and methods).

The concept of the pyrome was first introduced by Archibald *et al.* (*71*) as a pyrogeographical counterpart to the biogeographical concept of the biome. Biomes are defined not only by their observable biological characteristics but also by climatic and other environmental controls that cause particular biological characteristics to arise. In past work, pyromes have been characterized only by observable fire characteristics such as size, duration, intensity, and frequency (*71*–*74*). Here, we expand the pyrome concept to include a systematic grouping of ecoregions based on the strength of climatic and other environmental controls on fire. This approach enriches the pyrome concept with a dimension that mirrors the complexity inherent in the study of biomes while also providing critical insights into the varying sensitivity of pyromes to different facets of global change. Delineating the global forest pyromes revealed a rapid increase in emissions from extratropical forest pyromes that exceeded declining emissions from tropical forest pyromes during 2001 to 2023. This increase demonstrates that climatic controls on forest fire are overwhelming human controls in global-scale fire emissions trends.

Results

Twelve global forest pyromes emerged from the clustering analysis (Fig. 1), and this grouping revealed large increases in forest fire C emissions in extratropical forest pyromes. By contrast, forest fire C emissions declined in tropical and subtropical forest pyromes.

Geography and traits of the pyromes

To characterize the key controls on fire in each pyrome, we examined the correlations between forest BA and each variable representing the fire controls among the constituent ecoregions of the pyromes (Fig. 2 and figs. S1 and S2). We consider the mean correlations within each pyrome to indicate sensitivity of the forest BA response to each control and consider these relationships to be a trait of a pyrome when at least 75 percent of the constituent ecoregions display a correlation of the same sign (Fig. 2 and figs. S1 and S2). Significant differences in correlation were observed in 58% of pairwise comparisons, indicating a robust grouping of the ecoregions into pyromes with distinctive fire controls (see Materials and methods). A more complete description of pyrome characteristics is provided in supplementary text 2.

Pyromes in extratropical forests

Pyromes ExTropF1 and ExTropF2 encompass the North American and Eurasian boreal forests, as well as some temperate and high-altitude tropical forests (Fig. 1). Forest BA in these pyromes correlates positively with fire weather and atmospheric instability, negatively with seasonal soil moisture, and shows no correlation with population density, agricultural land cover, and road density (Fig. 2 and figs. S1 and S2). ExTropF1, more common in North America, has BA strongly correlated with lightning flash density, indicating lightning as a key ignition source (*33*, *34*). In ExTropF2, more common in Eurasia, BA correlates with normalized difference vegetation index (NDVI) from the prior growing season, suggesting that previous climatic conditions affecting vegetation growth and the production of fine fuels bear an influence on subsequent fire extent (*75*, *76*). Forest fire extent in pyromes ExTropF1 and ExTropF2 is governed by different combinations of climatic factors affecting fuel moisture, fuel growth, and natural ignition.

Pyromes ExTropF3 and ExTropF4 include forests of Scandinavia, western Russia, and certain areas of North America, Europe, and China (Fig. 1). Although the BA in these pyromes correlates with fire weather, the strength of correlations is lower than that in ExTropF1 or ExTropF2 and is especially weak in ExTropF4 (Fig. 2 and figs. S1 and S2). Additionally, in ExTropF4, no correlation with soil moisture further indicates that fires are also relatively insensitive to water deficits (Fig. 2 and figs. S1 and S2). Weak correlations with most variables in ExTropF3 and ExTropF4 likely relate to infrequent burning in these stable humid climates (fig. S8 and table S1), which challenges diagnoses of controls on fire over a two-decade time period.

Pyromes in tropical forests

TropF1 and TropF2 are widespread in the tropical deforestation zones of Amazonia, Congo, and equatorial southeast Asia (Fig. 1). Forest BA correlates positively with population density, road density, agricultural land cover, and fire weather, and negatively with forest continuity and soil moisture (Fig. 2 and figs. S1 and S2). These traits characterize a region with widespread deforestation and degradation fires that, particularly in TropF2, are facilitated by dry conditions (*48*, *77*, *78*). TropF1, primarily in Amazonia and the Congo, shows a strong correlation with pasture cover (fig. S1), reflecting cattle ranching–driven deforestation (*79*, *80*). TropF2, found in Sumatra, Kalimantan, Borneo, Guianas, and southeast Russia, has stronger correlations with soil moisture and weaker correlations with population, roads, and pasture cover than TropF1, highlighting the particularly prominent role of drought in facilitating peak fire activity (*78*, *81*, *82*). Several forest ecoregions in southeast Russia, a global hotspot of extratropical forest loss through fire linked to forestry operations (*82*), are also grouped with TropF2 (Fig. 1).

TropF3 characteristically maps to older, heavily fragmented deforestation frontiers in Brazil, Mexico, West Africa, and some southeast Asian islands (Fig. 1) (*83*, *84*). In these areas, forest BA correlates positively with fire weather and negatively with soil moisture but not with population or agriculture density, most likely caused by saturation of ignition sources in these highly populated regions during fire-favorable weather conditions.

Pyromes in subtropical forests

SubTropF1, SubTropF2, and SubTropF3 span subtropical or dry tropical forest ecoregions in regions such as northern Colombia, Madagascar, northeast India, southeast Asia, Sri Lanka, East Africa, and drier parts of the Brazilian Atlantic forests (Fig. 1). BA consistently correlates with forest continuity and fuel stocks in these pyromes, in addition to fire weather (Fig. 2 and figs. S1 and S2). This indicates a tendency for greater fire extent when meteorological conditions allow, in locations where fuel production is greater or flammable natural landscapes are less fragmented (*15*, *49*). In SubTropF1 and SubTropF2, negative correlations with population density, cropland cover, and road density—particularly strong in SubTropF2—suggest reduced fire activity in the areas most fragmented by human activity. Lightning frequency often correlates with BA in SubTropF2, pointing toward a greater frequency of natural ignitions.

In contrast to SubTropF1 and SubTropF2, BA in SubTropF3 shows no consistent correlation with population density, cropland cover, or road density, indicating that natural factors (e.g., topographic and hydrological) are more important controls on fuel loads and continuity than human factors. SubTropF3 also lacks strong correlations between BA and soil moisture, indicating sensitivity to short-term, fire-prone weather rather than seasonal moisture deficits (*15*, *49*).

Pyromes in zones of fire suppression

The final two pyromes, SupZoF1 and SupZoF2, span tropical, subtropical, and temperate forest ecoregions and are common in regions with substantial fire management efforts, such as the southeast US, western US, southeast and western Australia, and parts of Iberia (Fig. 1). In these pyromes, forest BA negatively correlates with population density, road density, and agriculture, indicating reduced fire extent in proximity to human activities (*46*, *85*). Positive correlations with forest continuity and fire spread suggests that continuous forests facilitate fire spread, especially in topographically complex areas with fewer human activities (*46*, *86*).

Fire suppression, fuel load management, and community programs are in place to reduce fire extent in these areas (*46*, *87*). Despite these efforts, fires can still occur during fire-prone weather (*37*, *88*), and stronger positive correlations with fire weather and negative correlations with soil moisture in SupZoF2 suggest that climatic factors bear stronger influence on forest BA than in SupZoF1 (Fig. 2). In SupZoF1, forest BA often (but inconsistently) correlates with lightning frequency, highlighting the role of natural ignitions, an effect that is seen most strongly in southeast Australia (*89*) (fig. S2). Additionally, SupZoF1 shows a correlation between forest BA and vegetation productivity from the prior growing season, emphasizing the role of fuel production as a driver of fire extent (*9*, *42*, *90*).

Increased fire emissions in extratropical forest pyromes

Forest fire C emissions increased in several of the pyromes between 2001 and 2023 (Fig. 3); however, the most notable trend was a 194% increase in fire C emissions in pyrome ExTropF2 (+116 Tg C year^{-1}; table S1). This large increase in fire C emissions was driven by a 167% increase in forest BA (+35 thousand km^2 year^{-1}) and a 58% increase in C combustion rate (C emissions per unit BA; Fig. 3 and table S1). Increased forest BA was a widespread feature of the ecoregions in pyrome ExTropF2, with over half showing significant increases and fewer than 5% showing significant decreases (Fig. 4 and fig. S11). Consequently, the increases in forest fire C emissions were also widespread. For example, forest fire C emissions increased significantly in parts of Russia (east and northeast Siberian taiga), Europe (e.g., Balkan mixed forests, Pindus

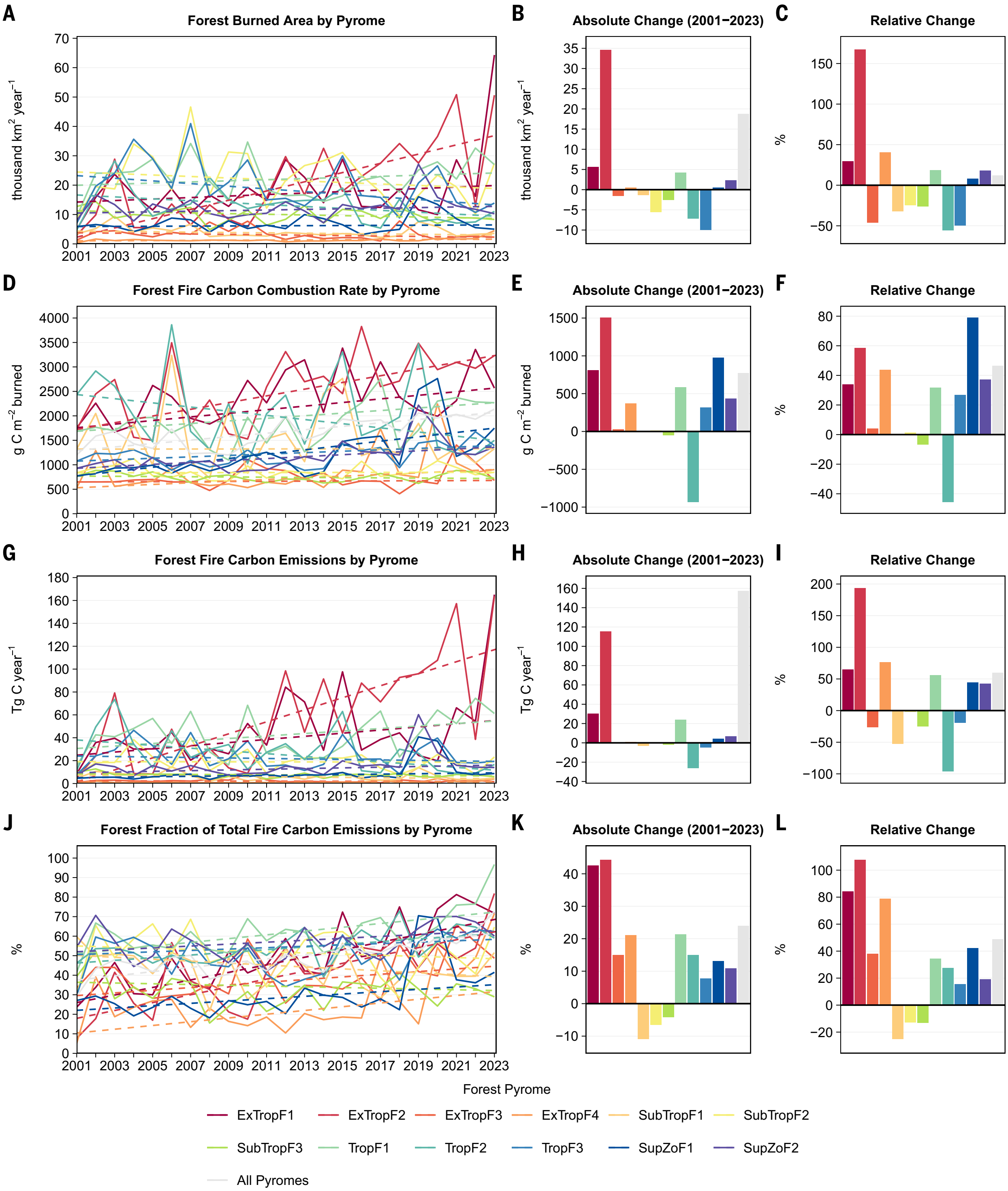

Fig. 3. Changes in BA in forests and carbon (C) emissions from forest fires during 2001 to 2023. By row, the panels show (**A**) to (**C**) forest BA, (**D**) to (**F**) fire C emissions per unit burned area of forest, (**G**) to (**I**) C emissions from forest fires, and (**J**) to (**L**) the forest fraction of total (forest plus non-forest) fire C emissions. By column the panels show (A), (D), (G), and (J) show annual data (solid lines) and trendlines (dashed lines) for each pyrome, (B), (E), (H), and (K) absolute changes during the data period, and (C), (F), (I), and (L) relative changes (%) for the same period. Trendlines are fitted using Theil-Sen regression. Fire C emissions are extrapolated for 2001 and 2023 based on the trend in C combustion rate during 2002 to 2020 and the observed annual BA in 2001 and 2023. Absolute changes are calculated as the difference between the trendline values at the start and end of the period, and relative changes are calculated conservatively as the absolute change divided by the period mean. Figures S3 to S5 present various aspects of forest and total (forest plus nonforest) fire trends, including changes in burned area, C emissions, and combustion rates. Figures S6 to S12 show mapped trends for individual forest ecoregions and the distribution of these values across the ecoregions of each pyrome.

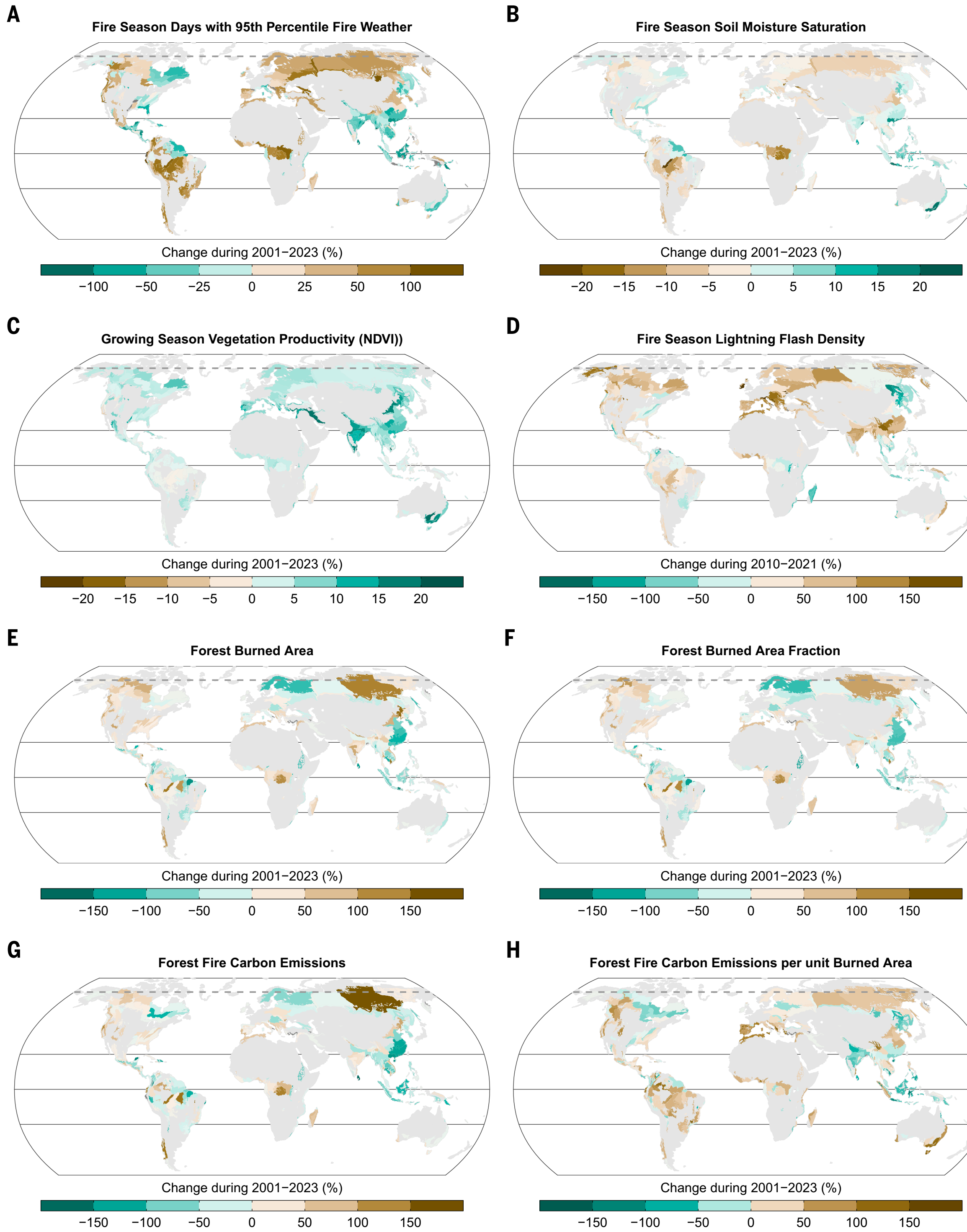

Fig. 4. Changes in bioclimatic variables and fire observations at ecoregion level. The panels show relative changes in four bioclimatic variables used to distinguish pyromes (**A**) to (**D**), forest burned area (BA) (**E**), forest burned area fraction (km^2 burned km^{-2} forest (**F**), forest fire carbon (C) emissions (**G**) and the forest fire C combustion rate (g C km^{-2} burned) during the period 2001 to 2023 (2010 to 2021 for lightning flash density), mapped to forest ecoregions. The climate variables are (a) days during the fire season with 95th percentile fire weather index (FWI) values relative to all days in the period 1980 to 2009, (B) average soil moisture content during the fire season, (C) mean normalized difference vegetation index (NDVI) during the prior growing season, and (D) lightning flash density during the fire season. The strength of the relationships between forest BA and fire weather, soil moisture, vegetation growth, and lightning varies across pyromes (Fig. 2) and there is lesser variability within the constituent ecoregions of each pyrome (figs. S1 and S2). Changes in forest fire C emissions (G) relate to changes in forest burned area (E) as well and emissions per unit BA (**H**). Figs. S6 to S17 additionally show the mapped mean values of these variables for individual ecoregions and the distribution of trends across the ecoregions of each pyrome.

and Dinaric mountains mixed forests), western North America (e.g., Sierra Nevada forests, North-Central Rockies forests, Muskwa-Slave lake forests, Fraser Plateau and Basin complex, and Northwest Territories taiga), Chile (Valdivian temperate forests), and China (Northeast China Plain deciduous forests and Hengduan Mountains conifer forests; Fig. 4).

The increases in forest BA and fire C emissions in pyrome ExTropF2 align with changes in the variables that control temporal variability in forest BA. During 2001 to 2023, the annual number of extreme fire weather days increased by 5 days per year on average across the ecoregions of the pyrome (Fig. 4, fig. S14, and table S2). The average soil moisture content during the fire season decreased by around 3% on average, in contrast to other extratropical pyromes where soil moisture either increased or remained level (Fig. 4, fig. S15, and table S2). Mean NDVI during the growing season also increased at a rate comparable to the other extratropical pyromes (Fig. 4, fig. S16, and table S2). These trends were also widespread and consistent. For example, over half of the ecoregions in pyrome ExTropF2 synchronously experienced an increase in extreme fire weather days, increased NDVI, and reduced soil moisture, with over one-quarter of ecoregions showing significant changes for all three variables. This evidence suggests that the trends in forest BA and fire C emissions in pyrome ExTropF2 were driven by changes in the climate of the fire season, which led to reduced fuel moisture, combined with changes in the climate of the growing season, which in turn led to increased vegetation growth and fuel production.

The increase in forest productivity during the growing season in pyrome ExTropF2 also corresponds with a 30% increase in forest area in the pyrome (+1 million km^2; fig. S3) during 2001 to 2023. This notable rate of forest expansion is consistent with reported rates exceeding 1% per year in some of these regions during 2001 and 2019 based on MODIS observations (*91*) and with the accumulating evidence for increased vegetation greenness and biomass stocks in the high latitudes (*76*, *92*, *93*). On the other hand, such a large increase in forest area has not been seen in Landsat-based estimates of change in forest cover, likely due to differences in resolution (see further discussion in Materials and methods) (*94*–*96*). Dual increases in forest area and productivity highlight how a warming climate and CO_2 fertilization have enhanced forest growth at higher latitudes and contributed to both a greater forest area available to burn and greater rates of fuel production (*97*, *98*). Nonetheless, growth in forest BA has outpaced growth in forest area, as indicated by a 158% increase in the fraction of forest area that burned annually during 2001 to 2023 (i.e., the forest BA fraction; table S1 and fig. S3).

Pyrome ExTropF1 also showed large and significant increases in forest BA (+30%, or 6000 km^2 per $year^{-1}$) and fire C emissions (+65%, or 30 Tg C $year^{-1}$) during 2001 to 2023, though these trends were not quite as pronounced as in pyrome ExTropF2 (Fig. 3 and table S1). Trends in forest BA were also more mixed among the ecoregions of pyrome ExTropF1, with around one-third showing a significant increase in forest BA and around 15% showing a significant decrease (Fig. 4, fig. S11 and table S1). The varied trends in forest BA can be explained by mixed trends in fire weather and soil moisture across the pyrome. The annual number of extreme fire weather days increased significantly in around 35% of the ecoregions of pyrome ExTropF1 but also decreased in 15%, whereas very few ecoregions experienced a significant increase in soil moisture (Fig. 4, figs. S14 and S15, and table S2). Only around 10% of ecoregions in pyrome ExTropF1 showed synchronous significant increases in extreme fire weather, soil moisture, and lightning density, which are the three key controls on fire activity that emerged from our clustering analysis in this pyrome (Fig. 2 and figs. S1 and S2).

Increased fire emissions in pyromes with fire suppression

In pyromes SupZoF1 and SupZoF2, forest fire C emissions increased by 43 to 44% during 2001 to 2023 (Fig. 3 and table S1). In both pyromes SupZoF1 and SupZoF2, the increased fire C emissions were driven primarily by significant 37 to 79% increases in the C combustion rate, combined with smaller nonsignificant increases in forest BA of 8 to 18% (Fig. 3 and table S1). Within pyromes SupZoF1 and SupZoF2, significant increases in fire C emissions were spatially concentrated in forest ecoregions of Australia (e.g., Blue Mountains forests, Naracoorte woodlands, Jarrah-Karri forests), southern Europe (e.g., Southwest Iberian Mediterranean sclerophyllous forests, Northwest Iberian montane forests, and Aegean and Western Turkey sclerophyllous forests), the western USA (Klamath-Siskiyou and coastal forests and California interior chaparral and woodlands), and Madagascar (subhumid and lowland forests; Fig. 4). The large upticks in emissions from forests in the western US and eastern Australia during 2019 and 2020 (*17*, *18*) are clearly visible in the emission time series for pyromes SupZoF1 and SupZoF2 and influence the slope of the trends in these pyromes (Fig. 3).

Reduced fire emissions in tropical forests

Forest fire C emissions showed opposing trends in the pyromes occupying the tropical deforestation zones, with a 96% decline (−26 Tg C $year^{-1}$) in forest fire C emissions in pyrome TropF2 outweighing 56% increases (+24 Tg C $year^{-1}$) in forest fire C emissions in pyrome TropF1 (Fig. 3). In pyrome TropF1, the increase in fire C emissions was caused by an increase in forest fire C combustion rate combined with a 19% increase in forest BA (Fig. 3 and table S1). Increased forest BA was widespread throughout the pyrome, with around two-thirds of the constituent ecoregions of pyrome TropF1 showing an increase during 2001 to 2023 (Fig. 4 and table S1). In pyrome TropF2, the decline in forest fire C emissions was predominantly driven by a 56% reduction in forest BA (Fig. 3 and table S1). The reductions in fire C emissions were consistent across the ecoregions of pyrome TropF2, with around 80% of the constituent ecoregions of the pyrome showing a decrease during 2001 to 2023 (Fig. 4, fig. S11, and table S1).

Discussion

Our mapping of pyromes has revealed variation in the controls on forest fire extent across the world's forest ecoregions. The pyrome boundaries tend to align with the boundaries of climate zones or biomes (Fig. 1), though not precisely due to significant variation in the drivers of fire within those zones. The expected first-order patterns of macro-scale pyrogeography are apparent in the distinctive traits of fire control that emerge from the clustering analysis (Fig. 2 and figs. S1 and S2). For example, human controls on fire emerge as a stronger trait of the tropical pyromes than of the extratropical pyromes, consistent with the expectation that the tropical fire regime is dominated by human activities (*2*, *99*, *100*).

In the largest extratropical pyromes (ExTropF1 and ExTropF2), forest fires are influenced by climatic factors affecting fuel moisture during the fire season and variably by the production of vegetation fuels in the growing season or by opportunities for lightning ignition. The near tripling of fire C emissions in pyrome ExTropF2 can be explained by pervasive increases in fire-favorable weather during the fire season, increased vegetation productivity in the growing season, and expanding forest cover. Increased forest extent and productivity at higher latitudes have been linked to climate changes that are favorable for vegetation growth and CO_2 fertilization (*97*), and our results show that these trends have coupled with reduced fuel moisture to drive an increase in forest BA and fire C emissions in pyrome ExTropF2. The weaker increases in fire C emissions in pyrome ExTropF1 can be attributed to less consistent trends in fire-favorable weather across the pyrome.

During 2001 to 2023, forest fire C emissions grew by 60% across all forest ecoregions globally, principally driven by trends in the extratropical pyromes (Fig. 3 and table S1). Forest BA and fire C emissions were redistributed from tropical and subtropical pyromes to extratropical pyromes (Fig. 5). Amidst these geographical shifts, the C combustion rate of forest fires also increased by 47% across all forest ecoregions

Fig. 5. Geographical shifts in forest BA and fire carbon (C) emissions from the tropics to the extratropics during 2001 to 2023. The plot shows contributions of groups of forest pyromes in the tropics, subtropics, extratropics and zones of suppression to (**A**) and (**B**) forest BA in all forest ecoregions globally and (**C**) and (**D**) the fire C emissions in all forest ecoregions globally. By column the panels show (A) and (C) annual data (solid lines) and trendlines (dashed lines) for each pyrome, (B) and (D) relative changes during 2001 to 2023. Trendlines are fitted using Theil-Sen regression. Fire C emissions are extrapolated for 2001 and 2023 based on the trend in C combustion rate during 2002 to 2020 and the observed annual BA in 2001 and 2023. Absolute changes are calculated as the difference between the trendline values at the start and end of the period, and relative changes are calculated conservatively as the absolute change divided by the period mean.

globally, reflecting greater fuel consumption per unit of forest BA (Fig. 3 and table S1). Extreme examples of C combustion per unit area have been recorded during recent extreme wildfire episodes and tied to extremes in fire-favorable weather (*8*, *11*, *16*, *17*, *101*), whereas our findings support a more general trend toward increases in fuel consumption in forests. In addition, the contribution of forest fires to total (forest plus nonforest) BA and fire C emissions has also increased globally and in most forest pyromes, with the exception of the subtropical forest pyromes (Fig. 3 and table S1), signaling that the increased susceptibility of forests to fire has generally outpaced that of nonforest environments experiencing similar environmental changes.

Our mapping of the pyromes enabled us to link rising fire C emissions in extratropical forests to climate change. For example, without distinguishing pyrome ExTropF2 and the climatic factors that influence its forest BA, the increase in fire emissions that has occurred there could be overlooked or masked. The emissions trend in pyrome ExTropF2 potentially signals that a step change in the fire regime and a destabilization of forest C stocks is underway in some extratropical ecoregions. Recent studies have identified a rise in forest productivity and fire-favorable weather as compounding drivers of increased fire C emissions in Siberia (16, 102–104), whereas our results indicate that similar dynamics are leading to increased fire C emissions more broadly across the ecoregions of pyrome ExTropF2.

Even in the pyromes where nonclimatic factors, particularly in situ human activities, exert significant control on forest BA, climatic factors remain a key enabler of fire. Increased fire weather under climate change can be expected to increase the windows of opportunity for fires to occur even in regions with significant fire suppression (31, 105, 106). For example, the uptick in the forest BA and fire C emissions in the pyromes SupZoF1 and SupZoF2, which encompass many zones of aggressive fire suppression and management, are consistent with warnings that the effectiveness of wildfire suppression is waning in a warming climate (107, 108). These findings highlight a potential for the relationships between climate and fire to strengthen in future climates.

Forest ecoregions with the most ambiguous cluster assignment (as measured by silhouette width statistics), are scattered globally with little tendency to concentrate in particular world regions (fig. S21), suggesting that the pyromes arising from our clustering procedure were largely free of regional bias (supplementary text 1). One exception is the Iberian Peninsula, where almost all ecoregions showed low silhouette widths, indicating a relatively low parity with other world regions. Among pyromes, clustering ambiguity was highest in SubTropF3, SupZoF1, and SupZoF2, with the most common alternative assignments to pyromes ExTropF1, ExTropF2, ExTropF3, ExTropF4, and SubTropF3, indicating a higher level of confusion between various climate-sensitive and extratropical pyromes (supplementary text 1).

Overall, we have contributed a new geographical mapping of forest pyromes based on distinctive fire drivers and discovered significant increases in forest BA and fire C emissions in some of the pyromes where they are most expected. Our work complements previous studies that used machine learning to disentangle the effect of multiple fire controls on global patterns or trends in BA (7, 40, 55, 56). For example, prior studies also indicated that increased vegetation productivity and fire-favorable weather both contributed to increased BA in boreal Eurasia during 2001 to 2014 (7, 40). Our explicit focus on forest BA and fire C emissions has also provided insights. For example, we find strong spatial contrasts in the effect of human activities on forest BA across different tropical and subtropical pyromes, whereas prior work indicated that human activities reduce total BA more uniformly across the tropics (7, 40).

Our work complements prior endeavors to define pyromes based on observable fire characteristics (72–75). While a novel and insightful aspect of our study is its focus on grouping regions with similar fire drivers, by doing so, we concentrated exclusively on BA as a target variable, foregoing information about other observable fire traits that vary geographically and are important aspects of the fire regime. Future work could aim to integrate geographical distinctions in both fire traits and fire drivers to provide a more holistic definition of the pyrome. This approach would further enhance the analogy with the term "biome," which encapsulates both the biological properties and physical presentation of grouped ecosystems, as well as the climatic and other environmental factors that cause those properties to emerge.

Looking forward, our pyrome classification could play a key role in the development of global fire models to better represent observed fire dynamics by creating opportunities to tailor model parameters in regions with distinct fire drivers. For example, parameters that represent the influence of people on fire processes could be optimized by pyrome in dynamic global vegetation models (DGVMs) to better represent the distinct relationships between human activities and fire across pyromes, in a manner akin to optimizing biological processes across plant functional types. Moreover, the pyrome layer also serves to highlight priority areas for the study of changes in fire weather, drought or vegetation productivity, since some pyromes are distinctly more sensitive to changes in these factors than others.

A caveat of our approach is that it provides a global zonation of fire controls at the macroscale—a scale that is particularly suited to questions concerning global environmental change, including differential responses to climate change. We do not suggest that all areas within an ecoregion are uniformly sensitive to the same fire controls. For example, differences in land use and management approaches across landowner types can be expected to produce varying relationships between fire and human factors within an ecoregion, as seen between protected areas, Indigenous areas, and private land (109, 110). Hence, our analysis identifies the dominant controls that emerge at the ecoregion scale but omits the local effects associated with specific actors at subecoregion level. The application of similar techniques to smaller (or larger) world regions would provide a finer (or coarser) geography of fire controls to which a different set of environmental questions may apply. In addition, our mapping of pyromes should not be viewed as fixed in time. For example, regional changes in policy, land use or population dynamics or ongoing shifts in climate or vegetation types could all lead to the reallocation of an ecoregion to a different pyrome in the future (74).

Relatedly, although our analysis provides valuable insights into the impacts of climate change on fire dynamics over a two-decade period, it is important to recognize the limitations inherent in using relatively short datasets to interpret fire regimes that operate over much longer intervals. Many forest ecosystems are subject to fire return intervals spanning decades to centuries, which can obscure the detection of longer-term trends. This is particularly the case in pyromes ExTropF3 and ExTropF4, where long fire return intervals (~1000 years; figure S7 and table S1) likely contributed to low correlations between BA and all explanatory variables and challenged the identification of fire drivers by clustering. Therefore, while our findings indicate significant trends such as the increase in emissions in the extratropics, increased combustion rates, and a shift from savannas and grasslands to forests as major fire emissions sources, these must be interpreted with some caution. Future studies extending beyond the 20-year time frame are essential to fully understand the long-term fire regimes and validate the persistence of such trends (9, 111).

Both observations and models suggest that extratropical forests are greening and becoming more productive due to a combination of climate change and CO_2 fertilization (97, 98, 112). DGVMs also generally project that C storage will continue to increase in the future in high latitude forests, although some variability is seen across models and climate scenarios (113, 114). Nonetheless, DGVMs currently show a limited capacity to reproduce historical trends and contemporary spatial patterns of fire (6, 115), raising concerns as to whether future change in fire disturbance is reliably captured in projections of future vegetation distribution and C storage. Additional uncertainty in future C storage stems from the potential for post-fire ecosystem shifts to occur due to increased fire severity not captured by models (116, 117). Our finding of increased forest fire C emissions lends further support to previous warnings that fire could offset projected gains in C storage in extratropical forests (118–120).

As forest fire C emissions grow, so does their relevance to carbon accounting, including the greenhouse gas (GHG) inventories submitted to the United Nations (UN). For example, C emissions from wildfires in Canada during 2023 alone are likely to have overturned a significant portion of the C sink to Canadian forests that accumulated over the prior decade (19, 121, 122). Wildfires in Canada are not free of anthropogenic influence and are becoming more likely due to anthropogenic climate change (19), yet they are designated as natural disturbances in Canada's national emissions inventory and thus their influence is largely omitted from UN records (*121*, *122*). Prior work has advocated for more comprehensive reporting of fire emissions on both managed and unmanaged land, to facilitate routine assessments of how fires impact national and global inventories of anthropogenic emissions (*121*). Our work further highlights the importance of this comprehensive reporting by revealing the growing role that forest fire C emissions play in the carbon budget of boreal forests.

Relatedly, enhancing C storage in forests using forestry practices is viewed as a promising strategy for C dioxide removal (CDR) from the atmosphere to offset anthropogenic C emissions (*123*, *124*). One recent study estimated that an additional 60 Pg C could be stored on extratropical land that is highly suitable for forestry (*125*), or 600 to 3000 Tg C year^{-1} when annualized over a period of 20 to 100 years representing the time taken for potential C stocks to accumulate (*126*). The estimates of potential C storage from (*125*) derive from relationships fitted to the C stocks held in current intact forests, yet these forests were established in historical fire regimes inferring that potential C storage is overestimated in forests where fire regime shifts are underway. For a crude comparison, we estimate that forest fire C emissions grew by 146 Tg C year^{-1} across all extratropical pyromes between 2001 and 2023 (table S1). We suggest that a continued increase in forest BA and fire C emissions could reduce the potential for CDR in extratropical forests by a nontrivial margin, particularly in the absence of effective fuel and fire management.

Although climatic factors show a varying strength of control on the extent of forest fires across pyromes, their effects are nonetheless pervasive. This result emphasizes the need to address the primary causes of climate change, by reducing emissions from fossil and land use sources, to mitigate the increased fire-related risks to C sinks (*127*, *128*). Moreover, our findings inform forest management and Net Zero policies by identifying pyromes where specific human actions can support forest C sinks by reducing C emissions from fires. In tropical pyromes, where fire shows a strong dependence on human ignition patterns, reducing ignitions during extreme fire-favorable weather and preventing forest fragmentation should enhance C retention (*30*, *129*). In pyromes with a history of aggressive wildfire suppression, shifting focus and funds from active fire suppression to managed, ecologically beneficial fires may prevent C sink-to-source conversion (*7*, *30*, *130*). In extratropical pyromes where climatic factors have the most direct and unmodulated control on fire extent, monitoring changes in vegetation and productivity can guide the prioritization of areas for forest management (*7*, *30*, *130*). In all pyromes, substantial financing is required to support strategic programs of forest management, stakeholder engagement, and public education, all of which represent a meaningful shift of fire management strategy from largely reactive to increasingly proactive (*7*, *30*, *130*). Overall, global forest C sinks could be undermined by wildfire without action to address the leading causes of climate change, while forest management strategies for mitigating the problem are likely to be most effective when tailored to pyromes. Irrespective of mitigation and adaptation measures, cutting anthropogenic emissions is central to securing resilient forests for the future.

REFERENCES AND NOTES

1. L. T. Kelly *et al*., Fire and biodiversity in the Anthropocene. *Science* **370**, eabb0355 (2020). doi: 10.1126/science.abb0355; pmid: 33214246
2. D. M. J. S. Bowman *et al*., Fire in the Earth system. *Science* **324**, 481–484 (2009). doi: 10.1126/science.1163886; pmid: 19390038
3. G. Lasslop *et al*., Global ecosystems and fire: Multi-model assessment of fire-induced tree-cover and carbon storage reduction. *Glob. Change Biol.* **26**, 5027–5041 (2020). doi: 10.1111/gcb.15160; pmid: 32407565
4. W. M. Jolly *et al*., Climate-induced variations in global wildfire danger from 1979 to 2013. *Nat. Commun.* **6**, 7537 (2015). doi: 10.1038/ncomms8537; pmid: 26172867
5. J. T. Abatzoglou, A. P. Williams, Impact of anthropogenic climate change on wildfire across western US forests. *Proc. Natl. Acad. Sci. U.S.A.* **113**, 11770–11775 (2016). doi: 10.1073/pnas.1607171113; pmid: 27791053
6. M. W. Jones *et al*., Global and Regional Trends and Drivers of Fire Under Climate Change. *Reviews of Geophysics* **60**, e2020RG000726 (2022). doi: 10.1073/pnas.1607171113; pmid: 27791053
7. United Nations Environment Programme, "Spreading like Wildfire – The Rising Threat of Extraordinary Landscape Fires" (UNEP, 2022); https://www.unep.org/resources/report/spreading-wildfire-rising-threat-extraordinary-landscape-fires.
8. B. Zheng *et al*., Increasing forest fire emissions despite the decline in global burned area. *Sci. Adv.* **7**, eabh2646 (2021). doi: 10.1126/sciadv.abh2646; pmid: 34559570
9. J. G. Canadell *et al*., Multi-decadal increase of forest burned area in Australia is linked to climate change. *Nat. Commun.* **12**, 6921 (2021). doi: 10.1038/s41467-021-27225-4; pmid: 34836974
10. A. P. Williams *et al*., Observed Impacts of Anthropogenic Climate Change on Wildfire in California. *Earths Futur.* **7**, 892–910 (2019). doi: 10.1029/2019EF001210
11. E. Ponomarev, N. Yakimov, T. Ponomareva, O. Yakubailik, S. G. Conard, Current Trend of Carbon Emissions from Wildfires in Siberia. *Atmosphere* **12**, 559 (2021). doi: 10.3390/atmos12050559
12. S. A. Parks, J. T. Abatzoglou, Warmer and Drier Fire Seasons Contribute to Increases in Area Burned at High Severity in Western US Forests From 1985 to 2017. *Geophys. Res. Lett.* **47**, e2020GL089858 (2020). doi: 10.1029/2020GL089858
13. L. V. Gatti *et al*., Amazonia as a carbon source linked to deforestation and climate change. *Nature* **595**, 388–393 (2021). doi: 10.1038/s41586-021-03629-6; pmid: 34262208
14. J. R. Marlon *et al*., Long-term perspective on wildfires in the western USA. *Proc. Natl. Acad. Sci. U.S.A.* **109**, E535–E543 (2012). doi: 10.1073/pnas.1112839109; pmid: 22334650
15. N. Andela *et al*., A human-driven decline in global burned area. *Science* **356**, 1356–1362 (2017). doi: 10.1126/science.aal4108; pmid: 28663495
16. B. Zheng *et al*., Record-high CO_2 emissions from boreal fires in 2021. *Science* **379**, 912–917 (2023). doi: 10.1126/science.ade0805; pmid: 36862792
17. I. R. van der Velde *et al*., Vast CO_2 release from Australian fires in 2019-2020 constrained by satellite. *Nature* **597**, 366–369 (2021). doi: 10.1038/s41586-021-03712-y; pmid: 34526704
18. P. E. Higuera, J. T. Abatzoglou, Record-setting climate enabled the extraordinary 2020 fire season in the western United States. *Glob. Change Biol.* **27**, 1–2 (2021). doi: 10.1111/gcb.15388; pmid: 33048429
19. M. W. Jones *et al*., State of Wildfires 2023–2024. *Earth Syst. Sci. Data* **16**, 3601–3685 (2024). doi: 10.5194/essd-16-3601-2024
20. M. Ward *et al*., Impact of 2019-2020 mega-fires on Australian fauna habitat. *Nat. Ecol. Evol.* **4**, 1321–1326 (2020). doi: 10.1038/s41559-020-1251-1; pmid: 32690905
21. D. B. Lindenmayer, C. Taylor, New spatial analyses of Australian wildfires highlight the need for new fire, resource, and conservation policies. *Proc. Natl. Acad. Sci. U.S.A.* **117**, 12481–12485 (2020). doi: 10.1073/pnas.2002269117; pmid: 32424092
22. C. Yue *et al*., How have past fire disturbances contributed to the current carbon balance of boreal ecosystems? *Biogeosciences* **13**, 675–690 (2016). doi: 10.5194/bg-13-675-2016
23. S. P. Harrison *et al*., The biomass burning contribution to climate–carbon-cycle feedback. *Earth Syst. Dyn.* **9**, 663–677 (2018). doi: 10.5194/esd-9-663-2018
24. D. M. J. S. Bowman, G. J. Williamson, O. F. Price, M. N. Ndalila, R. A. Bradstock, Australian forests, megafires and the risk of dwindling carbon stocks. *Plant Cell Environ.* **44**, 347–355 (2021). doi: 10.1111/pce.13916; pmid: 33068312
25. C. A. Phillips *et al*., Escalating carbon emissions from North American boreal forest wildfires and the climate mitigation potential of fire management. *Sci. Adv.* **8**, eabl7161 (2022). doi: 10.1126/sciadv.abl7161; pmid: 35476444
26. D. M. J. S. Bowman *et al*., Human exposure and sensitivity to globally extreme wildfire events. *Nat Ecol Evol* **1**, 0058 (2017). doi: 10.1126/sciadv.abl7161; pmid: 35476444
27. D. Wang *et al*., Economic footprint of California wildfires in 2018. *Nat. Sustain.* **4**, 252–260 (2021). doi: 10.1038/s41893-020-00646-7
28. F. H. Johnston *et al*., Unprecedented health costs of smoke-related PM2.5 from the 2019–20 Australian megafires. *Nat. Sustain.* **4**, 42–47 (2021). doi: 10.1038/s41893-020-00610-5
29. H. Clarke *et al*., Forest fire threatens global carbon sinks and population centres under rising atmospheric water demand. *Nat. Commun.* **13**, 7161 (2022). doi: 10.1038/s41467-022-34966-3; pmid: 36418312
30. World Bank Group, "World Bank Policy Note: Managing Wildfires in a Changing Climate" (WBG, 2020); https://www.profor.info/sites/default/files/PROFOR_ManagingWildfires_2020_final.pdf
31. J. T. Abatzoglou, A. P. Williams, R. Barbero, Global Emergence of Anthropogenic Climate Change in Fire Weather Indices. *Geophys. Res. Lett.* **46**, 326–336 (2019). doi: 10.1029/2018GL080959
32. J. T. Abatzoglou, C. A. Kolden, J. K. Balch, B. A. Bradley, Controls on interannual variability in lightning-caused fire activity in the western US. *Environ. Res. Lett.* **11**, 045005 (2016). doi: 10.1088/1748-9326/11/4/045005
33. S. Veraverbeke *et al*., Lightning as a major driver of recent large fire years in North American boreal forests. *Nat. Clim. Chang.* **7**, 529–534 (2017). doi: 10.1038/nclimate3329
34. T. A. J. Janssen *et al*., Extratropical forests increasingly at risk due to lightning fires. *Nat. Geosci.* **16**, 1136–1144 (2023). doi: 10.1038/s41561-023-01322-z
35. G. A. Mills, W. L. McCaw, Centre for Australian Weather and Climate Research, "Atmospheric Stability Environments and Fire Weather in Australia: Extending the Haines Index" (CAWCR Technical report no. 20, 2010).
36. G. Di Virgilio *et al*., Climate Change Increases the Potential for Extreme Wildfires. *Geophys. Res. Lett.* **46**, 8517–8526 (2019). doi: 10.1029/2019GL083699
37. G. J. van Oldenborgh *et al*., Attribution of the Australian bushfire risk to anthropogenic climate change. *Nat. Hazards Earth Syst. Sci.* **21**, 941–960 (2021). doi: 10.5194/nhess-21-941-2021
38. M. C. Kirchmeier-Young, F. W. Zwiers, N. P. Gillett, A. J. Cannon, Attributing extreme fire risk in Western Canada to human emissions. *Clim. Change* **144**, 365–379 (2017). doi: 10.1007/s10584-017-2030-0; pmid: 32009687
39. J. G. Pausas, J. E. Keeley, Wildfires and global change. *Front. Ecol. Environ.* **19**, 387–395 (2021). doi: 10.1002/fee.2359
40. D. I. Kelley *et al*., How contemporary bioclimatic and human controls change global fire regimes. *Nat. Clim. Chang.* **9**, 690–696 (2019). doi: 10.1038/s41558-019-0540-7
41. D. M. J. S. Bowman *et al*., Vegetation fires in the Anthropocene. *Nat. Rev. Earth Environ.* **1**, 500–515 (2020). doi: 10.1038/s43017-020-0085-3
42. N. J. Abram *et al*., Connections of climate change and variability to large and extreme forest fires in southeast Australia. *Commun. Earth Environ.* **2**, 8 (2021). doi: 10.1038/s43247-020-00065-8
43. L. E. O. C. Aragão *et al*., 21st Century drought-related fires counteract the decline of Amazon deforestation carbon

emissions. *Nat. Commun.* **9**, 536 (2018). doi: 10.1038/s41467-017-02771-y; pmid: 29440640
44. J. K. Balch *et al*., Human-started wildfires expand the fire niche across the United States. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 2946–2951 (2017). doi: 10.1073/pnas.1617394114; pmid: 28242690
45. P. M. Fernandes, A. P. Pacheco, R. Almeida, J. Claro, The role of fire-suppression force in limiting the spread of extremely large forest fires in Portugal. *Eur. J. For. Res.* **135**, 253–262 (2016). doi: 10.1007/s10342-015-0933-8
46. F. Moreira *et al*., Wildfire management in Mediterranean-type regions: Paradigm change needed. *Environ. Res. Lett.* **15**, 011001 (2020). doi: 10.1088/1748-9326/ab541e
47. R. A. Bradstock *et al*., Modelling the potential for prescribed burning to mitigate carbon emissions from wildfires in fire-prone forests of Australia. *Int. J. Wildland Fire* **21**, 629–639 (2012). doi: 10.1071/WF11023
48. C. H. L. Silva Junior *et al*., Persistent collapse of biomass in Amazonian forest edges following deforestation leads to unaccounted carbon losses. *Sci. Adv.* **6**, eaaz8360 (2020). doi: 10.1126/sciadv.aaz8360; pmid: 32998890
49. T. M. Rosan *et al*., Fragmentation-Driven Divergent Trends in Burned Area in Amazonia and Cerrado. *Front. For. Glob. Change* **5**, 801408 (2022). doi: 10.3389/ffgc.2022.801408
50. M.-A. Parisien *et al*., Fire deficit increases wildfire risk for many communities in the Canadian boreal forest. *Nat. Commun.* **11**, 2121 (2020). doi: 10.1038/s41467-020-15961-y; pmid: 32358496
51. B. M. Rogers, A. J. Soja, M. L. Goulden, J. T. Randerson, Influence of tree species on continental differences in boreal fires and climate feedbacks. *Nat. Geosci.* **8**, 228–234 (2015). doi: 10.1038/ngeo2352
52. M. L. Pettinari, E. Chuvieco, Generation of a global fuel data set using the Fuel Characteristic Classification System. *Biogeosciences* **13**, 2061–2076 (2016). doi: 10.5194/bg-13-2061-2016
53. M. Forkel *et al*., Emergent relationships with respect to burned area in global satellite observations and fire-enabled vegetation models. *Biogeosciences* **16**, 57–76 (2019). doi: 10.5194/bg-16-57-2019
54. J. T. Abatzoglou, A. P. Williams, L. Boschetti, M. Zubkova, C. A. Kolden, Global patterns of interannual climate-fire relationships. *Glob. Change Biol.* **24**, 5164–5175 (2018). doi: 10.1111/gcb.14405; pmid: 30047195
55. M. Forkel *et al*., A data-driven approach to identify controls on global fire activity from satellite and climate observations (SOFIA V1). *Geosci. Model Dev.* **10**, 4443–4476 (2017). doi: 10.5194/gmd-10-4443-2017
56. E. Chuvieco *et al*., Human and climate drivers of global biomass burning variability. *Sci. Total Environ.* **779**, 146361 (2021). doi: 10.1016/j.scitotenv.2021.146361; pmid: 34030254
57. D. M. Olson *et al*., Terrestrial Ecoregions of the World: A New Map of Life on Earth. *Bioscience* **51**, 933 (2001). doi: 10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2
58. L. Giglio, L. Boschetti, D. P. Roy, M. L. Humber, C. O. Justice, The Collection 6 MODIS burned area mapping algorithm and product. *Remote Sens. Environ.* **217**, 72–85 (2018). doi: 10.1016/j.rse.2018.08.005; pmid: 30220740
59. D. van Wees *et al*., Global biomass burning fuel consumption and emissions at 500 m spatial resolution based on the Global Fire Emissions Database (GFED). *Geosci. Model Dev.* **15**, 8411–8437 (2022). doi: 10.5194/gmd-15-8411-2022
60. C. E. Van Wagner, "Development and Structure of the Canadian Forest Fire Weather Index System" (Canadian Forestry Service, Forestry Technical Report 351987, 1987); https://cfs.nrcan.gc.ca:443/publications?id=19927.
61. C. Vitolo *et al*., ERA5-based global meteorological wildfire danger maps. *Sci. Data* **7**, 216 (2020). doi: 10.1038/s41597-020-0554-z; pmid: 32636392
62. J. Muñoz-Sabater *et al*., ERA5-Land: A state-of-the-art global reanalysis dataset for land applications. *Earth Syst. Sci. Data* **13**, 4349–4383 (2021). doi: 10.5194/essd-13-4349-2021
63. R. H. Holzworth *et al*., Lightning in the Arctic. *Geophys. Res. Lett*. **48**, e2020GL091366 (2021). doi: 10.5194/essd-13-4349-2021
64. A. Huete *et al*., Overview of the radiometric and biophysical performance of the MODros. Inf. Serv. vegetation indices. *Remote Sens. Environ.* **83**, 195–213 (2002). doi: 10.1016/S0034-4257(02)00096-2
65. K. Didan, MOD13A3 - MODIS/Terra Vegetation Indices Monthly L3 Global 1km SIN Grid, NASA LP DAAC (2021); http://doi.org/10.5067/MODIS/MOD13A3.006.
66. J. E. Dobson, E. A. Bright, P. R. Coleman, R. C. Durfee, B. A. Worley, LandScan: A global population database for estimating populations at risk. *Photogramm. Eng. Remote Sensing* **66**, 849–857 (2000).
67. M. Friedl, D. Sulla-Menashe, MCD12Q1 - MODIS/Terra+Aqua Land Cover Type Yearly L3 Global 500m SIN Grid, NASA LP DAAC (2019); http://doi.org/10.5067/MODIS/MCD12Q1.006.
68. T. P. Robinson *et al*., Mapping the global distribution of livestock. *PLOS ONE* **9**, e96084 (2014). doi: 10.1371/journal.pone.0096084; pmid: 24875496
69. J. R. Meijer, M. A. J. Huijbregts, K. C. G. J. Schotten, A. M. Schipper, Global patterns of current and future road infrastructure. *Environ. Res. Lett.* **13**, 064006 (2018). doi: 10.1088/1748-9326/aabd42
70. G. Amatulli, D. McInerney, T. Sethi, P. Strobl, S. Domisch, Geomorpho90m, empirical evaluation and accuracy assessment of global high-resolution geomorphometric layers. *Sci. Data* **7**, 162 (2020). doi: 10.1038/s41597-020-0479-6; pmid: 32467582
71. S. Archibald, C. E. R. Lehmann, J. L. Gómez-Dans, R. A. Bradstock, Defining pyromes and global syndromes of fire regimes. *Proc. Natl. Acad. Sci. U.S.A.* **110**, 6442–6447 (2013). doi: 10.1073/pnas.1211466110; pmid: 23559374
72. M. E. Cattau, A. L. Mahood, J. K. Balch, C. A. Wessman, Modern Pyromes: Biogeographical Patterns of Fire Characteristics across the Contiguous United States. *Fire* **5**, 95 (2022). doi: 10.3390/fire5040095
73. M. García *et al*., Characterizing Global Fire Regimes from Satellite-Derived Products. *Forests* **13**, 699 (2022). doi: 10.3390/f13050699
74. C. X. Cunningham *et al*., Pyrogeography in flux: Reorganization of Australian fire regimes in a hotter world. *Glob. Change Biol.* **30**, e17130 (2024). doi: 10.1111/gcb.17130; pmid: 38273509
75. M. Forkel *et al*., Extreme fire events are related to previous-year surface moisture conditions in permafrost-underlain larch forests of Siberia. *Environ. Res. Lett.* **7**, 044021 (2012). doi: 10.1088/1748-9326/7/4/044021
76. V. I. Kharuk, M. L. Dvinskaya, S. T. Im, A. S. Golyukov, K. T. Smith, Wildfires in the Siberian Arctic. *Fire (Basel)* **5**, 106 (2022). doi: 10.3390/fire5040106
77. P. M. Brando *et al*., Droughts, Wildfires, and Forest Carbon Cycling: A Pantropical Synthesis. *Annu. Rev. Earth Planet. Sci.* **47**, 555–581 (2019). doi: 10.1146/annurev-earth-082517-010235
78. T. Nikonovas, A. Spessa, S. H. Doerr, G. D. Clay, S. Mezbahuddin, Near-complete loss of fire-resistant primary tropical forest cover in Sumatra and Kalimantan. *Commun. Earth Environ.* **1**, 1–8 (2020). doi: 10.1038/s43247-020-00069-4
79. J. Barlow, E. Berenguer, R. Carmenta, F. França, Clarifying Amazonia's burning crisis. *Glob. Change Biol.* **26**, 319–321 (2020). doi: 10.1111/gcb.14872; pmid: 31729092
80. V. R. Pivello, The Use of Fire in the Cerrado and Amazonian Rainforests of Brazil: Past and Present. *Fire Ecol* **7**, 24–39 (2011). doi: 10.1111/gcb.14872; pmid: 31729092
81. R. D. Field, G. R. van der Werf, S. S. P. Shen, Human amplification of drought-induced biomass burning in Indonesia since 1960. *Nat. Geosci.* **2**, 185–188 (2009). doi: 10.1038/ngeo443
82. P. G. Curtis, C. M. Slay, N. L. Harris, A. Tyukavina, M. C. Hansen, Classifying drivers of global forest loss. *Science* **361**, 1108–1111 (2018). doi: 10.1126/science.aau3445; pmid: 30213911
83. M. R. Rosa *et al*., Hidden destruction of older forests threatens Brazil's Atlantic Forest and challenges restoration programs. *Sci. Adv.* **7**, eabc4547 (2021). doi: 10.1126/sciadv.abc4547; pmid: 33523918
84. J. C. Aleman, M. A. Jarzyna, A. C. Staver, Forest extent and deforestation in tropical Africa since 1900. *Nat. Ecol. Evol.* **2**, 26–33 (2018). doi: 10.1038/s41559-017-0406-1; pmid: 29230024
85. Y. Le Page, D. Oom, J. M. N. Silva, P. Jönsson, J. M. C. Pereira, Seasonality of vegetation fires as modified by human action: Observing the deviation from eco-climatic fire regimes. *Glob. Ecol. Biogeogr.* **19**, 575–588 (2010). doi: 10.1111/j.1466-8238.2010.00525.x
86. M. Castellnou *et al*., Empowering strategic decision-making for wildfire management: avoiding the fear trap and creating a resilient landscape. *Fire Ecol* **15**, 31 (2019). doi: 10.1111/j.1466-8238.2010.00525.x
87. H. Hesseln, Wildland Fire Prevention: A Review. *Curr. For. Rep.* **4**, 178–190 (2018). doi: 10.1007/s40725-018-0083-6
88. J. T. Abatzoglou *et al*., Projected increases in western US forest fire despite growing fuel constraints. *Commun. Earth Environ.* **2**, 1–8 (2021). doi: 10.1038/s43247-021-00299-0
89. H. Clarke, R. Gibson, B. Cirulis, R. A. Bradstock, T. D. Penman , Developing and testing models of the drivers of anthropogenic and lightning-caused wildfire ignitions in south-eastern Australia. *J. Environ. Manage.* **235**, 34–41 (2019). doi: 10.1016/j.jenvman.2019.01.055; pmid: 30669091
90. R. A. Bradstock, A biogeographic model of fire regimes in Australia: current and future implications: A biogeographic model of fire in Australia. *Glob. Ecol. Biogeogr.* **19**, 145–158 (2010). doi: 10.1111/j.1466-8238.2009.00512.x
91. R. Rotbarth *et al*., Northern expansion is not compensating for southern declines in North American boreal forests. *Nat. Commun.* **14**, 3373 (2023). doi: 10.1038/s41467-023-39092-2; pmid: 37291123
92. L. T. Berner, S. J. Goetz, Satellite observations document trends consistent with a boreal forest biome shift. *Glob. Change Biol.* **28**, 3275–3292 (2022). doi: 10.1111/gcb.16121; pmid: 35199413
93. H. Yang *et al*., Global increase in biomass carbon stock dominated by growth of northern young forests over past decade. *Nat. Geosci.* **16**, 886–892 (2023). doi: 10.1038/s41561-023-01274-4
94. Y. Li *et al*., Inconsistent estimates of forest cover change in China between 2000 and 2013 from multiple datasets: Differences in parameters, spatial resolution, and definitions. *Sci. Rep.* **7**, 8748 (2017). doi: 10.1038/s41598-017-07732-5; pmid: 28821759
95. H. Yin, A. Khamzina, D. Pflugmacher, C. Martius, Forest cover mapping in post-Soviet Central Asia using multi-resolution remote sensing imagery. *Sci. Rep.* **7**, 1375 (2017). doi: 10.1038/s41598-017-01582-x; pmid: 28465582
96. X. Wei *et al*., Monitoring forest dynamics in Africa during 2000–2020 using a remotely sensed fractional tree cover dataset. *Int. J. Digit. Earth* **16**, 2212–2232 (2023). doi: 10.1080/17538947.2023.2220613
97. S. Piao *et al*., Characteristics, drivers and feedbacks of global greening. *Nat. Rev. Earth Environ.* **1**, 14–27 (2020). doi: 10.1038/s43017-019-0001-x
98. Y. He *et al*., CO_2 fertilization contributed more than half of the observed forest biomass increase in northern extra-tropical land. *Glob. Change Biol.* **29**, 4313–4326 (2023). doi: 10.1111/gcb.16806; pmid: 37277951
99. S. L. Lewis, D. P. Edwards, D. Galbraith, Increasing human dominance of tropical forests. *Science* **349**, 827–832 (2015). doi: 10.1126/science.aaa9932; pmid: 26293955
100. S. Archibald, Managing the human component of fire regimes: Lessons from Africa. *Philos. Trans. R. Soc. Lond. B Biol. Sci.* **371**, 20150346 (2016). doi: 10.1098/rstb.2015.0346; pmid: 27216516
101. Q. Xu *et al*., Wildfire burn severity and emissions inventory: An example implementation over California. *Environ. Res. Lett.* **17**, 085008 (2022). doi: 10.1088/1748-9326/ac80d0
102. E. A. Kukavskaya, E. G. Shvetsov, L. V. Buryak, P. D. Tretyakov, P. Y. Groisman, Increasing Fuel Loads, Fire Hazard, and Carbon Emissions from Fires in Central Siberia. *Fire (Basel)* **6**, 63 (2023). doi: 10.3390/fire6020063
103. R. C. Scholten, D. Coumou, F. Luo, S. Veraverbeke, Early snowmelt and polar jet dynamics co-influence recent extreme Siberian fire seasons. *Science* **378**, 1005–1009 (2022). doi: 10.1126/science.abn4419; pmid: 36454839
104. E. I. Ponomarev, A. N. Zabrodin, E. G. Shvetsov, T. V. Ponomareva, Wildfire Intensity and Fire Emissions in Siberia. *Fire (Basel)* **6**, 246 (2023). doi: 10.3390/fire6070246
105. T. D. Hessilt *et al*., Future increases in lightning ignition efficiency and wildfire occurrence expected from drier fuels in boreal forest ecosystems of western North America. *Environ. Res. Lett.* **17**, 054008 (2022). doi: 10.1088/1748-9326/ac6311
106. J. K. Shuman *et al*.,Reimagine fire science for the anthropocene. *PNAS Nexus*, **1** pgac115 (2022). doi: 10.1088/1748-9326/ac6311; pmid: 36741468
107. M. A. Cochrane, D. M. J. S. Bowman, Manage fire regimes, not fires. *Nat. Geosci.* **14**, 455–457 (2021). doi: 10.1038/s41561-021-00791-4
108. S. Bloem, A. C. Cullen, L. O. Mearns, J. T. Abatzoglou, The Role of International Resource Sharing Arrangements in Managing Fire in the Face of Climate Change. *Fire* **5**, 88 (2022). doi: 10.3390/fire5040088
109. C. F. Starrs, V. Butsic, C. Stephens, W. Stewart, The impact of land ownership, firefighting, and reserve status on fire probability in California. *Environ. Res. Lett.* **13**, 034025 (2018). doi: 10.1088/1748-9326/aaaad1

110. A. C. M. Pessôa *et al*., Protected areas are effective on curbing fires in the Amazon. *Ecol. Econ.* **214**, 107983 (2023). doi: 10.1016/j.ecolecon.2023.107983
111. C. C. Hanes *et al*., Fire-regime changes in Canada over the last half century. *Can. J. For. Res.* **49**, 256–269 (2019). doi: 10.1139/cjfr-2018-0293
112. P. Friedlingstein *et al*., Global Carbon Budget 2023. *Earth Syst. Sci. Data* **15**, 5301–5369 (2023). doi: 10.5194/essd-15-5301-2023
113. S. Sitch *et al*., Evaluation of the terrestrial carbon cycle, future plant geography and climate-carbon cycle feedbacks using five Dynamic Global Vegetation Models (DGVMs). *Glob. Change Biol.* **14**, 2015–2039 (2008). doi: 10.1111/j.1365-2486.2008.01626.x
114. C.-E. Yang *et al*., Uncertainty Quantification of Extratropical Forest Biomass in CMIP5 Models over the Northern Hemisphere. *Sci. Rep.* **8**, 10962 (2018). doi: 10.1038/s41598-018-29227-7; pmid: 30026558
115. S. Kloster, G. Lasslop, Historical and future fire occurrence (1850 to 2100) simulated in CMIP5 Earth System Models. *Global Planet. Change* **150**, 58–69 (2017). doi: 10.1016/j.gloplacha.2016.12.017
116. M. C. Mack *et al*., Carbon loss from boreal forest wildfires offset by increased dominance of deciduous trees. *Science* **372**, 280–283 (2021). doi: 10.1126/science.abf3903; pmid: 33859032
117. J. L. Baltzer *et al*., Increasing fire and the decline of fire adapted black spruce in the boreal forest. *Proc. Natl. Acad. Sci. U.S.A.* **118**, e2024872118 (2021). doi: 10.1073/pnas.2024872118; pmid: 34697246
118. M. S. Balshi *et al*., Vulnerability of carbon storage in North American boreal forests to wildfires during the 21st century. *Glob. Change Biol.* **15**, 1491–1510 (2009). doi: 10.1111/j.1365-2486.2009.01877.x
119. S. Schaphoff, C. P. O. Reyer, D. Schepaschenko, D. Gerten, A. Shvidenko, Tamm Review: Observed and projected climate change impacts on Russia's forests and its carbon balance. *For. Ecol. Manage.* **361**, 432–444 (2016). doi: 10.1016/j.foreco.2015.11.043
120. M. R. Turetsky *et al*., Recent acceleration of biomass burning and carbon losses in Alaskan forests and peatlands. *Nat. Geosci.* **4**, 27–31 (2011). doi: 10.1038/ngeo1027
121. J. MacCarthy, A. Tyukavina, M. J. Weisse, N. Harris, E. Glen, Extreme wildfires in Canada and their contribution to global loss in tree cover and carbon emissions in 2023. *Glob. Change Biol.* **30**, e17392 (2024). doi: 10.1111/gcb.17392; pmid: 38934256
122. Government of Canada, "National inventory report: greenhouse gas sources and sinks in Canada" (2024); publications.gc.ca/pub?id=9.506002&sl=0
123. B. W. Griscom *et al*., Natural climate solutions. *Proc. Natl. Acad. Sci. U.S.A.* **114**, 11645–11650 (2017). doi: 10.1073/pnas.1710465114; pmid: 29078344
124. H. B. Smith, N. E. Vaughan, J. Forster, Long-term national climate strategies bet on forests and soils to reach net-zero. *Commun. Earth Environ.* **3**, 1–12 (2022). doi: 10.1038/s43247-022-00636-x
125. W. S. Walker *et al*., The global potential for increased storage of carbon on land. *Proc. Natl. Acad. Sci. U.S.A.* **119**, e2111312119 (2022). doi: 10.1073/pnas.2111312119; pmid: 35639697
126. B. K. Haya *et al*., Comprehensive review of carbon quantification by improved forest management offset protocols. *Front. For. Glob. Change* **6**, 2023 | (2023). doi: 10.3389/ffgc.2023.958879
127. IPCC, "Summary for Policymakers" in Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, V. Masson-Delmotte *et al*., Eds. (Cambridge Univ. Press, 2021), pp. 3–32.
128. S. Smith *et al*., "The state of carbon dioxide removal" (University of Oxford's Smith School of Enterprise and the Environment, 2024); https://osf.io/w3b4z/
129. J. Barlow *et al*., The critical importance of considering fire in REDD+ programs. *Biol. Conserv.* **154**, 1–8 (2012). doi: 10.1016/j.biocon.2012.03.034
130. Organisation for Economic Cooperation and Development (OECD), "Taming Wildfires in the Context of Climate Change" (OECD, 2023); https://www.oecd-ilibrary.org/environment/taming-wildfires-in-the-context-of-climate-change_dd00c367-en.
131. M. W. Jones, Supplementary Data: Global rise in forest fire emissions linked to climate change in the extratropics, Zenodo (2024); https://doi.org/10.5281/zenodo.10036942.
132. D. van Wees *et al*., "Global biomass burning fuel consumption and emissions at 500-m spatial resolution based on the Global Fire Emissions Database (GFED)," version v2, Zenodo (2024); https://doi.org/10.5281/zenodo.12670427.
133. G. R. van der Werf *et al*., Global fire emissions estimates during 1997–2016. *Earth Syst. Sci. Data* **9**, 697–720 (2017). doi: 10.5194/essd-9-697-2017

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SUPPLEMENTARY MATERIALS

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Materials and Methods
Supplementary Texts 1 and 2
Figs. S1 to S22
Tables S1 to S2
References (*134*–*180*)

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WILDFIRES

The fastest-growing and most destructive fires in the US (2001 to 2020)

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The most destructive and deadly wildfires in US history were also fast. Using satellite data, we analyzed the daily growth rates of more than 60,000 fires from 2001 to 2020 across the contiguous US. Nearly half of the ecoregions experienced destructive fast fires that grew more than 1620 hectares in 1 day. These fires accounted for 78% of structures destroyed and 61% of suppression costs ($18.9 billion). From 2001 to 2020, the average peak daily growth rate for these fires more than doubled (+249% relative to 2001) in the Western US. Nearly 3 million structures were within 4 kilometers of a fast fire during this period across the US. Given recent devastating wildfires, understanding fast fires is crucial for improving firefighting strategies and community preparedness.

Some of the most deadly and destructive wildfires in US history have occurred in recent years, with most having the common characteristic of extremely rapid growth. The 2018 Camp Fire in California burned >21,000 ha the day it started, killing 85 people and destroying >16,000 homes. The 2021 Marshall Fire, the most destructive wildfire in Colorado history, was driven by winds >100 mph; it traveled 3 miles within the hour it started and burned >1000 homes. The 2023 Lahaina Fire in Hawaii killed 101 people and destroyed >2200 structures when a small brush fire escaped containment and burned through the town to the shore in 2 hours. The modern era of megafires is often defined based on wildfire size (*1*), but it should be defined based on how fast fires grow and their consequent societal impacts. Speed fundamentally dictates the deadly and destructive impact of megafires, rendering the prevailing paradigm that defines them by size inadequate. Although big fires change air quality, ecosystems, and carbon dynamics (*2*), fire speed matters more for infrastructure risk and evacuation planning (*3*).

The scientific community has explored trends in extreme fire size (*4*, *5*) and burn severity (*6*) and documented increasing burned areas across the Western US (*7*). Further, we know that fast fires occur when it is hot, dry, and windy, but relatively little research exists about when and why they occur across regional or national scales. Most of the area burned in extremely large events is from the growth on a single day, which is driven by extreme fire weather (*8*). Moreover, the frequency of fast-growing fires is predicted to increase by ~50 to 200% with projected warming (*9*, *10*). Humans also ignite fires in areas closer to structures (*3*) and during times with more extreme fire weather (*11*), both of which result in more destructive fires (*12*). Recent observational evidence is corroborated by empirical models (*13*) that derive relationships to predict fire growth (*14*) and drive landscape fire simulations for individual events (*15*, *16*). Such fire behavior models inform wildfire risk models suggesting that the most deadly and damaging wildfires are also some of the fastest (*17*, *18*). How fast fires burn also affects burn severity, spatial complexity (*19*, *20*), and synchronicity (*21*). However, we do not know the patterns, drivers, and consequences of fast fires on a national scale.

Fire suppression policies, logging, the proliferation of invasive species, climate change, and anthropogenic ignition patterns have fundamentally altered the fire-evolved landscapes of postcolonial America (*22*–*28*). Moreover, the expansion of the urban footprint (*29*) has placed tens of millions of homes squarely into this contemporary fuel matrix, which is called the wildland-urban interface (WUI) (*30*). The rapid expansion of this footprint has occurred largely without regard for wildfire risk, either through building policies or comprehensive community planning (*31*). As a result, nearly 60 million homes in the US were threatened by a wildfire between 1992 and 2015 (*3*), a number that has likely increased substantially in the intervening years due to record fires in California, Oregon, and Colorado. The wildfire risk models currently used at a national scale are based on probability of occurrence and area burned, intensity, or severity (*21*, *32*–*35*) rather than on how fast wildfires could move. This lack of attention to fire growth is a critical risk assessment gap, particularly given the rapid expansion of the WUI into areas with the greatest probability of wildfire (*36*, *37*) and the mechanisms by which most homes burn. We know that the primary mechanism for home ignition is firebrands propelled ahead of the flaming front that land on flammable materials attached to, on, or inside the structure and ultimately consume it (*38*). Firefighters can extinguish these building ignitions during slower fires or when structure ignition is mitigated (*39*), but during fast-moving events, they are often overwhelmed by the higher number of homes catching fire simultaneously and the need to focus on life safety and evacuations, such as during the 2018 Camp Fire (*17*).

Our lack of understanding is linked to our lack of national data on fire growth rates (FGRs) across events. Recent data on individual fire events and how they progressed, coupled with fine-grained settlement data, enable us to explore how fast fires move at a national scale and how that affects residential exposure. We developed a Fire Event Delineation (FIRED) perimeter dataset for >60,000 fire events (*40*). This dataset is derived from daily burn date estimations from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) Burned Area Product (*41*), enabling calculation and investigation of daily FGR. FGR derived from satellite-detected burned area on a daily basis is different from, but related to, how fast a burning fireline moves on the ground. Settlement data have also become available to measure trends of development over long time periods at fine resolution (*29*). The Historical Settlement Data Compilation of the US (HISDAC-US) (*42*, *43*), which is derived from >200 million property and housing records, allows us to estimate nearby exposure to wildfires (up to 4 km away). Government records during suppression activities (ICS-209-PLUS) enable us to further explore the societal consequences of wildfires by providing documentation on how many structures were damaged or destroyed on a daily basis during fire events (*25*, *44*). The aggregation of ICS-209 reports provides the best available information on the high costs of US wildfires at a national scale. The combination of these latter two datasets, HISDAC-US on the spatiotemporal distribution of residential structures and the ICS-209-PLUS on actual structure loss, allows us to explore both potential exposure and documented impact.

Given the critical need to understand fast-moving wildfires and the tens of millions of homes that stand in their paths, we analyzed fires in the context of their speed and damage to homes. We documented the fastest-growing fires in the US from 2001 to 2020, exploring the maximum single-day FGR across an event,

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hereafter referred to as "maximum FGR." We then related maximum FGR with structure loss (i.e., damaged or destroyed) to provide a societally relevant threshold for defining fast fires (maximum FGR > 1620 ha/day). Finally, we explored the trends in maximum FGR and how many total structures, specifically residences, were exposed to fast fires over the past two decades.

FGRs in the contiguous US

FGRs were highly variable across all events (N = 60,012), with fires growing at an average rate of 255 ha/day. Maximum FGR ranged from 21 to 214,200 ha/day, often multiple orders of magnitude greater than the mean FGR across the entire event (table S1). Burned area on the day of maximum FGR accounted for more than one-third (38%) of the area burned across the US (table S2), and >70% for some land cover types in certain ecoregions (e.g., shrublands in the Great Plains; table S2). The maximum FGR is very strongly associated with final fire size across land cover types (fig. S1), with the log-log relationship suggesting that it follows a power law distribution (adjusted R^2 = 0.97). The importance of this is that extreme fire weather on individual days is driving fire growth and has consequences for suppression efforts (*45*). Further, >90% of events last no longer than 20 days (fig. S2A), and 83% of events reach their maximum growth rate within 5 days across all ecoregions (fig. S2B). In addition, there are distinct temporal and spatial characteristics across different vegetation types (e.g., grassland fires burn large areas within a few days, whereas broadleaf forests sustain fire growth for longer periods of time; fig. S3). Many modeling efforts at regional to national scales model fire activity at monthly to yearly timescales (*4*, *46*). Our results highlight the need for regional models of fire behavior that use predictors at daily to hourly timescales rather than burned area estimations based on topography and spatiotemporally coarse climate data. This is particularly important in the context of modeling the occurrence of extreme meteorological events and their ability to drive rapid fire growth (*20*). Such models exist (*13*–*15*) and are being further advanced (*33*), but it remains to be tested whether they can replicate the remotely sensed spread rates in extreme events such as those discussed here. We also found that mean and maximum FGRs

Table 1. Top 20 fastest-growing fires across the CONUS from 2001 to 2020. Summary statistics describe the top 20 fastest fires from FIRED linked to their associated incident command system summary report (*44*). The top 20 fastest fires accrued an estimated $398 million in suppression costs alone, exposed 264,338 properties (within 4 km of a fire perimeter), and destroyed >9000 structures. Of the 20 fastest fires, 16 occurred primarily in grassland vegetation types (>50% grassland in burned area).

Incident name	Year	State(s)	Fire size (ha)	Maximum fire growth (ha/day)	Duration (days)	Cost (US dollars)	Properties exposed (*n*)	Structures destroyed (*n*)	Total aerial units (*n*)	Total personnel (*n*)	Dominant vegetation
NW Oklahoma Complex	2017	OK, KS	315,369	214,208	16	3,200,000	1647	151	2	955	Grasslands
Long Draw	2012	OR	225,664	129,911	14	4,360,000	2	0	49	4237	Grasslands
Cold Springs Complex	2020	WA	218,969	102,199	33	11,459,351	4907	288	34	4327	Grasslands
Perryton	2017	TX	128,753	100,911	14	NR	97	11	3	235	Grasslands
Anderson Creek	2016	OK, KS	148,819	81,420	19	1,750,000	1098	54	20	1183	Grasslands
Murphy Complex	2007	ID	263,862	70,150	30	13,000,000	21	3	56	10,443	Grasslands
East Amarillo Complex	2006	TX	367,149	60,770	23	NR	4821	89	6	702	Grasslands
Martin	2018	NV	176,269	59,246	20	8,500,000	0	1	97	2332	Grasslands
Milford Flat	2007	UT	146,922	58,258	16	5,050,000	112	2	25	4421	Grasslands
Glass	2008	TX	88,851	57,979	5	NR	1	0	8	56	Grasslands
Buzzard Complex	2014	OR	160,153	50,252	14	11,062,411	42	4	96	5265	Grasslands
August Complex	2020	CA	417,898	46,629	68	115,511,218	196	446	1153	63,814	Evergreen needle-leaf forests
Kinyon Road	2012	ID	85,338	47,461	12	1,625,000	57	0	18	1361	Grasslands
Soda	2015	ID	115,482	46,474	9	6,250,000	662	1	69	1706	Grasslands
Rhea	2018	OK	115,820	44,499	26	3,707,498	1669	32	62	941	Grasslands
North Complex	2020	CA	129,069	42,438	52	112,711,950	4607	2342	802	63,229	Evergreen needle-leaf forests
Cedar	2003	CA	110,579	41,408	18	32,616,213	132,444	2820	626	74,404	Closed shrublands
Cooper Mountain Ranch	2011	TX	65,812	39,969	13	1,194,159	740	0	8	854	Grasslands
LNU Lightning Complex	2020	CA	146,990	39,132	22	94,646,381	34,344	1479	354	36,601	Grasslands
Witch-Poomacha	2007	CA	80,124	38,639	19	18,000,000	76,871	1680	2	46,819	Closed shrublands

NR, not recorded.

vary by land cover and ecoregion, with the fastest-growing fires typically in the grasslands and savannas of arid ecoregions (table S3). The 10 fastest fires were in grassland-dominated vegetation, which highlights the role of fine, flashy fuels and low wind friction (Table 1 and table S4). The three wildfires highlighted in Fig. 1 show how fast fires can grow within the first few days.

Fast fires are also the most destructive and deadly ones

Although there has been substantial focus on megafires defined primarily by their size (*47*), we delineate a critical physical metric that links directly with impact: maximum daily FGR. Treating wildfires as social-environmental extremes (*48*) and defining a subset of events based on both their physical behavior and destructive impact advances our understanding and ability to prepare for such events (*49*). Fires growing faster than 1620 ha on any single day damage or destroy a large number of structures (Fig. 2). Regression tree analysis (residual mean deviance = 2.39) indicates that one of the best predictors of whether a large number of structures were damaged or destroyed across the entire event is whether the maximum FGR exceeded this threshold of 1620 ha (see the supplementary materials and methods). There is an association between the day of maximum daily growth and the day that structures were reported as being affected (fig. S4). This speed corresponds to the 97th percentile of maximum daily fire growth registered between 2001 and 2020, representing 1616 events out of 60,012 total events and 60.1% of the burned area in the FIRED record. Therefore, we define fast fires as events that grow >1620 ha on a single day (i.e., maximum FGR > 1620 ha/day). These fast fires represent only 2.7% of all events, yet they account for 89% of the total structures damaged or destroyed. It is important to note that this is a nationwide threshold based on fires that had any structure loss at all. Of the fires that damaged or destroyed >100 structures (N = 71), their average maximum daily growth was 8569 ha/day (median = 4916 ha/day). Moreover, there are important differences across states (table S5). For example, California has by far the highest structure loss compared with other states (N = 66,715 structures damaged or destroyed) and exhibits a fast fire threshold of 2870 ha/day.

Our results document that 58 of the 85 level 3 ecoregions in the contiguous US (CONUS) experienced more than one fast fire between 2001 and 2020 (fig. S5), representing an area of ~3,780,000 km^2 or 49% of CONUS land area. According to the ICS-209-PLUS fire suppression records (2001 to 2020) (*44*), fast fires threatened 1,780,476 structures (67% of total threatened) and resulted in $18.9 billion of suppression expenditures (61% of total). Moreover, 80,700 structures were destroyed (78% of total destroyed), and 57,883 were damaged (82% of total damaged) across this time period during fast fire events. This subset of fires represents a devastating impact to society, accounting for 337 fatalities (66% of total) and 5623 injuries (43% of total).

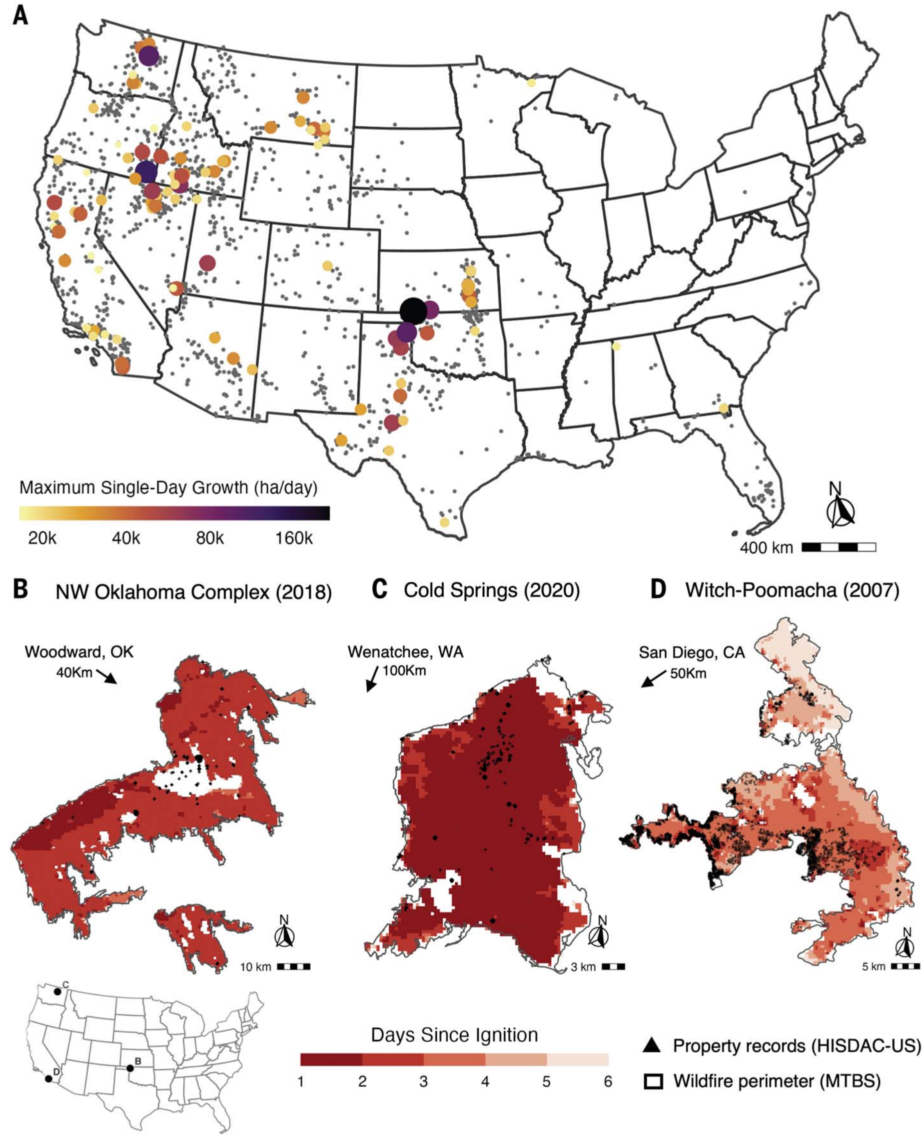

Fig. 1. Fast fires in the US. (**A**) Locations of all recorded fast fires from 2001 to 2020 (maximum FGR >1620 ha, N = 1616, in gray) in the CONUS with the top 100 fastest fires scaled in color and size by their maximum single-day fire growth rate in hectares/day. The fastest fires occurred primarily in the Western US and in the Southeastern Plains (Texas and Oklahoma), but across a wide range of ecoregions and fuel types. (**B** to **D**) Three examples of the fastest fires on record highlighting the daily burned area from the MODIS Burned Area Product (MCD64A1), fire perimeters from the Monitoring Trends in Burn Severity (MTBS), and approximate locations of properties within the burned area from the BUPR obtained from the HISDAC-US database. (B) The Northwest Oklahoma Complex Fire in 2018 is the fastest recorded fire in the database, with a single-day maximum growth of 214,208 ha/day, burning in grasslands. (C) The Cold Springs Fire in 2020 was part of the destructive Labor Day fires, which burned in high winds and, together with the Pearl Hill and Whitney fires, burned >165,000 ha in a matter of days. The Cold Springs Fire was the largest of the three and burned almost entirely in a single day (102,198 ha/day). (D) The Witch and Poomacha fires in 2003 burned just outside of San Diego, CA, directly exposing >8000 properties within days (with >76,000 properties within 4 km of the burned area) and destroying 1680 structures, making it one of the most destructive fast fires in the database.

From 2001 to 2020, fast fires grew even faster across much of the Western US

For all fires, mean FGR significantly increased in 38 and maximum FGR significantly increased in 20 of the 84 level III ecoregions (mainly in the Western US). Mean FGR significantly decreased in 16 and maximum FGR significantly

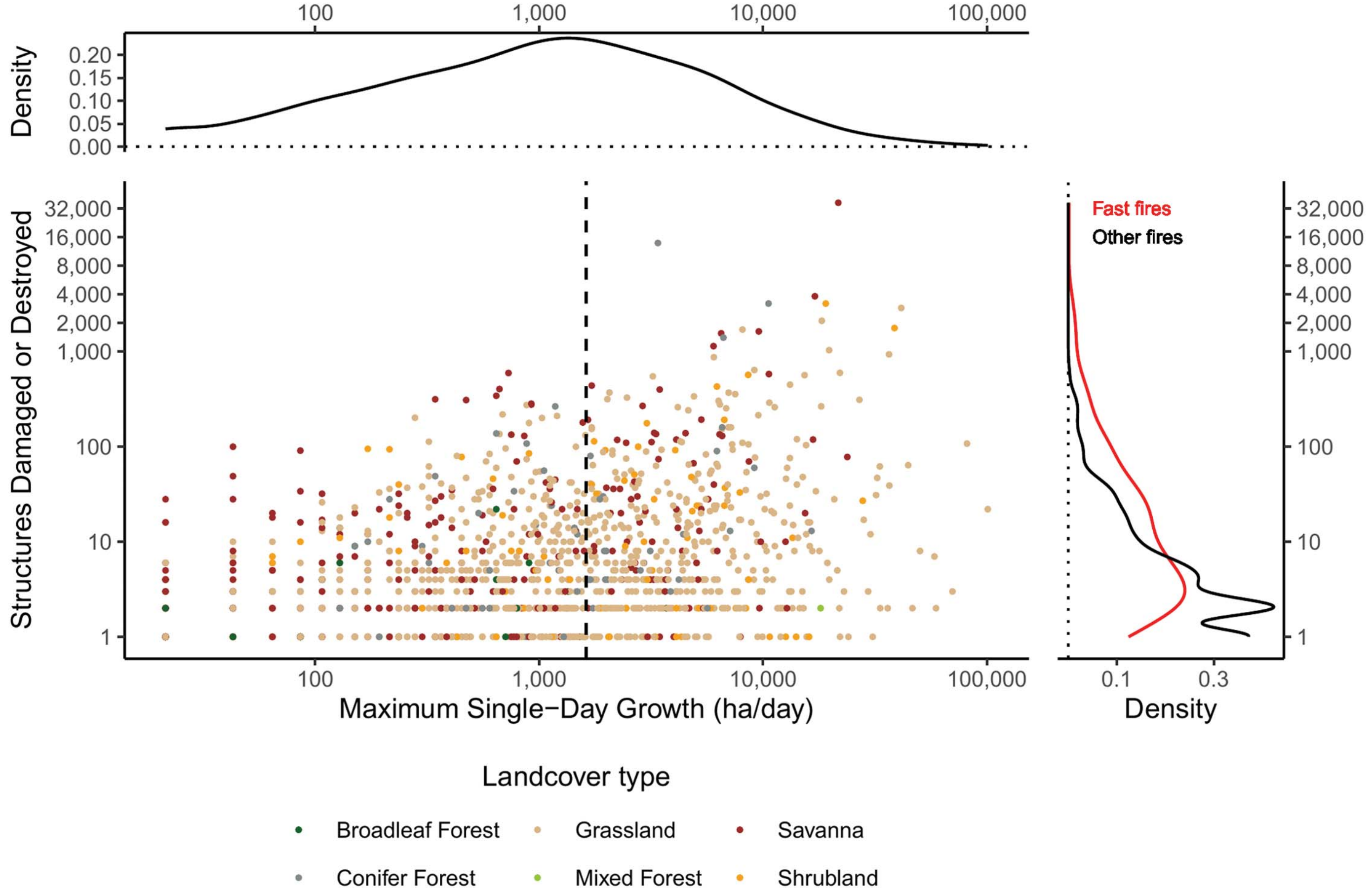

Fig. 2. Defining fast fires as a function of social-economic impacts. Scatterplot of log-transformed maximum FGR and log-transformed number of structures destroyed, with marginal probability density distributions. The dashed line shows the lower bound of growth of fast fires (1620 ha/day or above) that were also the most destructive ones. Note that the axes are in log scale and that only fast fires destroyed >600 structures.

decreased in nine of the ecoregions (mainly in the Northeast; Fig. 3 and fig. S6). Most of California's ecoregions, along with coastal Oregon and Washington state, exhibited an increase in FGR over this period. Most pronounced were the increases in event-level spread and daily growth rates in mediterranean California, with an increase of 300 ha/day in maximum daily growth in Southern California mountains (Theil-Sen coefficient = 15.0 ha/day/year; table S6). Across ecoregions in the state of California, the average maximum FGR increased by 4.2 ha/day/year (±0.4 SE), or ~80 ha/day across the 20-year record (table S7). The Snake River Plain and Columbia Plateau of the North American desert ecoregion also saw a substantial increase of >278 ha/day in maximum daily growth (Theil-Sen coefficient = 13.9 ha/day/year; table S6). Across ecoregions in 11 Western states, the mean of the maximum FGR increased by 2.1 ha/day/year (±0.1 SE), or ~40 ha/day across the 20-year record (table S7). On the basis of these trends, fires grew 249% faster (based on maximum daily FGR) across the Western US by the end of the 20-year record (table S8). In California, fires grew 398% faster

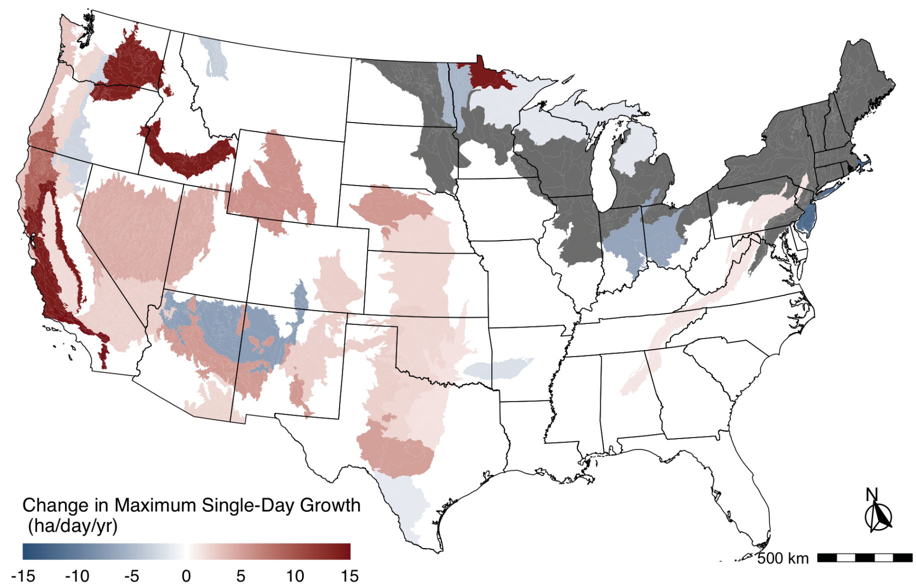

Fig. 3. Temporal trends in maximum annual fire growth on a given day for events longer than 4 days per Environmental Protection Agency (EPA) ecoregion level IV from 2001 to 2020. Statistically significant positive and negative regression coefficients ($P < 0.05$) are depicted in warm and cold colors, respectively. Regression coefficients that were not statistically significant from zero (i.e., no significant trend) are shown in white. Ecoregions without sufficient data for the analysis are indicated in gray.

(based on maximum FGR) by the end of the 20-year record (table S8). (These percentage increases in California and the Western US represent the mean of the maximum FGR in 2020 as a percentage of mean maximum FGR in 2001; see the materials and methods.) Across the Western US, this trend in growth has been accompanied by an increase in annual burned area near built-up areas (i.e., those <1 km from a residential structure) of 323% since 2001 (fig. S7).

Using the HISDAC-US Historical Built-up Property Records (BUPR) (*43*), we estimated that 184,917 properties were exposed directly to fast fires (e.g., within the fire perimeter), 722,017 structures were within 1 km of fast fire perimeters, and 2,948,501 structures were within 4 km of fast fire perimeters (Fig. 4 and fig. S8). Firebrands have ignited WUI materials several kilometers from the main fire (*39*), thus putting structures within this proximity at some risk of loss.

Conclusions: Fire speed matters

Wildfire events should be defined based on their speed, not just their size. Here, we provide a first look at understanding national patterns and trends (2001 to 2020) in FGR using a satellite-derived metric (*50*). There are two major implications of our work: (i) we define what constitutes "fast fires" and (ii) we demonstrate that fires are getting faster, particularly in the Western US.

Herein, we delineate a new class of the fastest-growing and most destructive fires, or fast fires. This class is akin to "mega-fires" but is defined based on a maximum daily growth rate of >1620 ha/day, where we document most of the structures destroyed (78%) and suppression costs (61%). A major advance is that this class of fast fires is defined by both the physical behavior and societal impact, representing coupled social-environmental extremes (*48*). We also demonstrate that there is a strong relationship between growth rate and burned area (fig. S1); growth is the fundamental mechanism driving final event size. Current national fire risk models and planning efforts tend to focus on fire probability, intensity, or area burned (*50*) rather than on fire speed and consequent settlement exposure or potential damage. Fast fires matter for life safety and structure impacts; large fires matter more for ecosystems and they generate substantial smoke. The speed of a fire determines (i) whether firefighters are more focused on evacuation than home protection (*17*) and (ii) how effectively they can extinguish burning firebrands and new ignitions on structures before the home becomes fully involved (*38*, *39*). Additionally, we quantify that the fastest-growing fires are in grassland systems, where more homes have been destroyed relative to forest wildfires (*51*), highlighting the need to rethink grassland fire management strategies.

We also document that fires are growing significantly faster across nearly half of the CONUS land area and 2.5 times faster across the Western US in just 20 years. Increasing speed will challenge emergency response, evacuation plans, and community preparedness (*52*). Incident command reports indicate that at least 925 emergency evacuation orders affected >1.5 million households between 2001 and 2020 (*44*), and approximately half of these were within 1 km of a fast fire (Fig. 4). Wildfire-related emergency evacuation success will be influenced by the density of human settlements, road access (*53*), and efficient use of early warning systems and information delivery to affected communities (*54*), all of which will be compromised by faster-moving fires. With maximum daily growth occurring within the first 5 days after ignition for 83% of all events (fig. S2B), we also need to focus on proactive measures

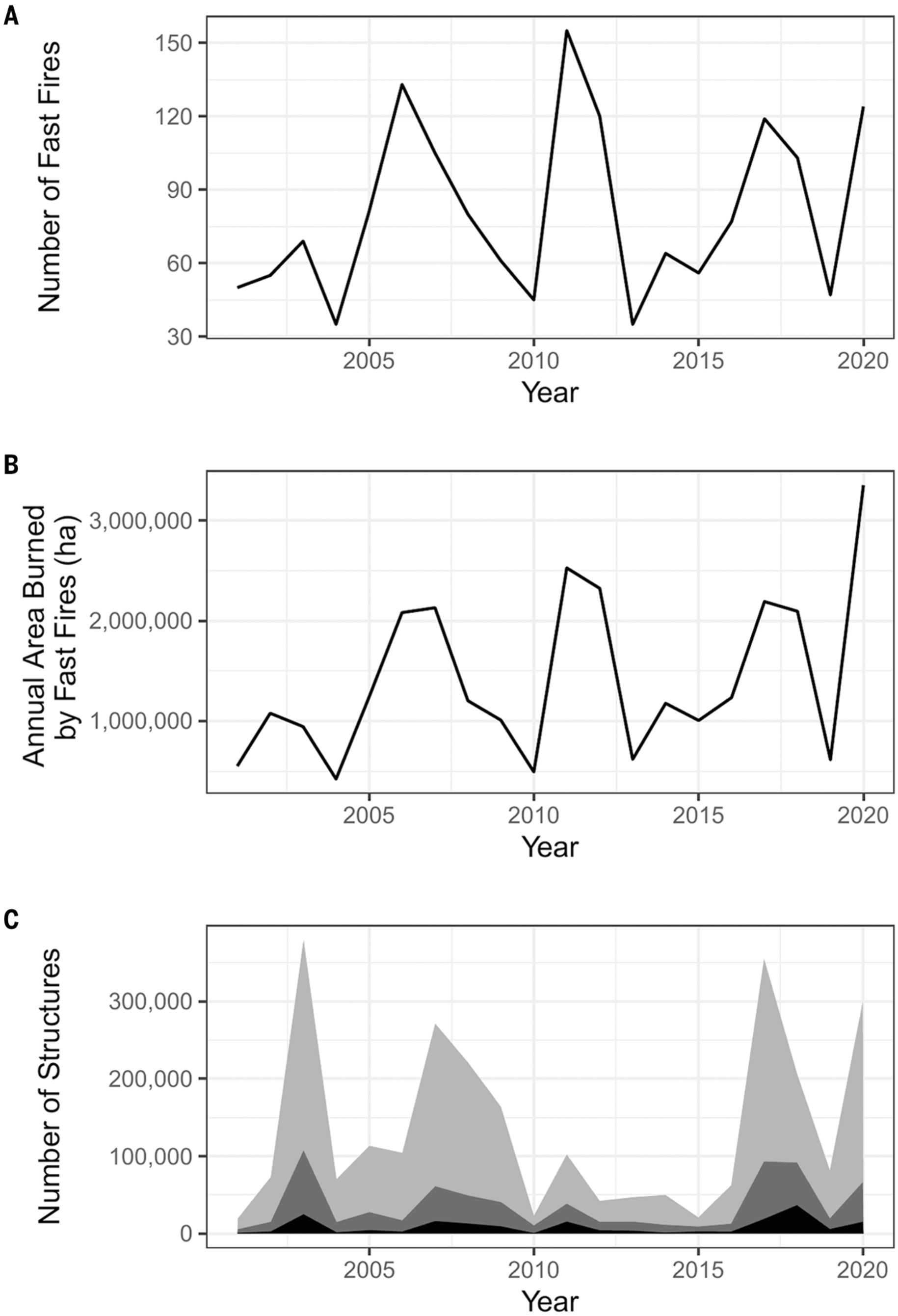

Fig. 4. Exposure to fast fires (>1620 ha/day) from 2001 to 2020. (**A**) Number of fast fires per year. (**B**) Annual area affected by fast fires. (**C**) Trends in the number of structures (based on the BUPR dataset) within the perimeters of fast fires (black), within 1 km of the perimeters of fast fires (dark gray), and within 4 km of the perimeters of fast fires (light gray).

that slow fires down or promote fire resilience of the built environment. We need to implement building codes that incentivize the use of fire-resistant materials (*55*), harden existing homes and remove flammable materials adjacent to structures (*56*), and preemptively plan for evacuation. Fuel mitigation efforts that will slow fires down include, for example, strategic wildland fuel breaks in the expected path of a fire and rethinking the constellation of proximate, flammable homes in new developments. Future research efforts will help us better understand the hourly progression of blow-ups from higher-resolution satellite sensors and how effective fire suppression teams may already be at slowing wildfires.

Fires may be growing faster due to warming trends, vegetation transitions to more flammable fuels, or the co-occurrence of high winds with increasing human-related ignitions. Climate-driven increases in burned area has been well documented in the US (*57*), as well as an observed tripling of fire frequency in the 2000s relative to the prior two decades (*21*). Many fast fires occur during downslope wind events coincident with anomalously dry autumn conditions, which increased both in frequency (25%) and in the area they burned (140%) from 1992 to 2020 (*58*). Juang *et al.* found that the increase in Western US forest fire area since the mid-1980s was driven almost exclusively by increasing sizes of the largest fires (*59*). The mechanism is a function of geometric growth: Larger fires tend to grow faster than smaller fires because longer firelines have greater potential for spread. It is also known that invasive grasses can drive increases in size (*23*), occurrence, and frequency (*24*). Because grass-fueled fires are some of the fastest (table S3), it may then follow that where vegetation transitions have occurred, for example, from forest or shrubland to invasive grassland (*60*), fire speed may have also increased. Further, we know that there is a relationship between human ignitions and higher winds (*11*, *61*), because lightning generally does not occur under high-wind conditions due to the constraints surrounding their associated storms (*61*). Across the US, there has been a steady increase (9%) in the percentage of wildfires started by humans since 1992 (*62*). It has yet to be tested whether the co-occurrence of windy conditions and human-related ignitions, such as downed power lines, is increasing. People start nearly all the wildfires that threaten our homes (*3*), making understanding of the ignition, climatic, and fuel drivers of fast fires an important area of future work.

The number of fast fire events that have destroyed >1000 homes in just the past 5 years is alarming (*63*) and may foreshadow what is coming in years ahead. Fast fires overall accounted for 88% of residential structures destroyed in the US from 2001 to 2020. With warming temperatures increasing the likelihood of wildfires across the US (*64*), we would expect to see more fast fire events in the future. Devastating and fast-moving wildfires, such as the Camp Wildfire in California, the Marshall Wildfire in Colorado, and the Lahaina Wildfire in Hawaii, show that it is critical that we plan for the increasing pace of fires.

REFERENCES AND NOTES

1. F. Tedim *et al*., *Fire* **1**, 9 (2018).
2. F. H. Johnston *et al*., *Nat. Sustain.* **4**, 42–47 (2021).
3. N. Mietkiewicz *et al*., *Fire* **3**, 50 (2020).
4. M. B. Joseph *et al*., *Ecol. Appl.* **29**, e01898 (2019).
5. R. C. Nagy, E. Fusco, B. Bradley, J. T. Abatzoglou, J. Balch, *Fire* **1**, 4 (2018).
6. S. A. Parks, J. T. Abatzoglou, *Geophys. Res. Lett.* **47**, e2020GL089858 (2020).
7. J. Buch, A. P. Williams, C. S. Juang, W. D. Hansen, P. Gentine, *Geosci. Model Dev.* **16**, 3407–3433 (2023).
8. B. E. Potter, D. McEvoy, *Earth Interact.* **25**, 160–176 (2021).
9. J. D. Coop, S. A. Parks, C. S. Stevens-Rumann, S. M. Ritter, C. M. Hoffman, *Glob. Ecol. Biogeogr.* **31**, 1949–1959 (2022).
10. P. T. Brown *et al*., *Nature* **621**, 760–766 (2023).
11. S. Hantson, N. Andela, M. L. Goulden, J. T. Randerson, *Nat. Commun.* **13**, 2717 (2022).
12. A. D. Syphard, J. E. Keeley, M. Gough, M. Lazarz, J. Rogan, *Fire* **5**, 133 (2022).
13. R. C. Rothermel, "A mathematical model for predicting fire spread in wildland fuels" (US Department of Agriculture, Intermountain Forest and Range Experiment Station, Research Paper INT-115, 1972); https://research.fs.usda.gov/treesearch/32533.
14. P. L. Andrews, "BEHAVE: Fire behavior prediction and fuel modeling system-BURN Subsystem, part 1" (US Department of Agriculture, Forest Service, Intermountain Research Station, General Technical Report INT-194, 1986); https://research.fs.usda.gov/treesearch/29612.
15. A. L. Sullivan, *Int. J. Wildland Fire* **18**, 349 (2009).
16. J. L. Coen, *Int. J. Wildland Fire* **14**, 49–59 (2005).
17. A. Maranghides *et al*., "A case study of the camp fire – Fire progression timeline" (NIST Technical Note 2135, 2021); https://doi.org/10.6028/NIST.TN.2135.
18. C. C. Wilson, *Int. Fire Chief* **43**, 9 (1977).
19. D. A. Falk *et al*., *Front. Ecol. Environ.* **9**, 446–454 (2011).
20. X. Wang, T. Swystun, J. Oliver, M. D. Flannigan, *Environ. Res. Lett.* **16**, 114031 (2021).
21. V. Iglesias, J. K. Balch, W. R. Travis, *Sci. Adv.* **8**, eabc0020 (2022).
22. J. K. Balch *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **114**, 2946–2951 (2017).
23. J. K. Balch, B. A. Bradley, C. M. D'Antonio, J. Gómez-Dans, *Glob. Chang. Biol.* **19**, 173–183 (2013).
24. E. J. Fusco, J. T. Finn, J. K. Balch, R. C. Nagy, B. A. Bradley, *Proc. Natl. Acad. Sci. U.S.A.* **116**, 23594–23599 (2019).
25. P. E. Higuera *et al*., *PNAS Nexus* **2**, pgad005 (2023).
26. C. Naficy, A. Sala, E. G. Keeling, J. Graham, T. H. DeLuca, *Ecol. Appl.* **20**, 1851–1864 (2010).
27. S. J. Pyne, *Fire in America: A Cultural History of Wildland and Rural Fire* (Univ. of Washington Press, 1997).
28. A. P. Williams, J. T. Abatzoglou, *Curr. Clim. Change Rep.* **2**, 1–14 (2016).
29. S. Leyk *et al*., *Sci. Adv.* **6**, eaba2937 (2020).
30. S. I. Stewart, V. C. Radeloff, R. B. Hammer, T. J. Hawbaker, *J. For.* **105**, 201–207 (2007).
31. H. A. Kramer *et al*., *Land Use Policy* **107**, 105502 (2021).
32. G. K. Dillon, J. P. Menakis, F. Fay, "Wildland fire potential: A tool for assessing wildfire risk and fuels management needs," in *Proceedings of the Large Wildland Fires Conference; May 19–23, 2014; Missoula, MT* (US Department of Agriculture, Forest Service, Rocky Mountain Research Station, RMRS-P-73, 2015).
33. M. A. Finney, C. W. McHugh, I. C. Grenfell, K. L. Riley, K. C. Short, *Stochastic Environ. Res. Risk Assess.* **25**, 973–1000 (2011).
34. J. R. Haas, D. E. Calkin, M. P. Thompson, *Landsc. Urban Plan.* **119**, 44–53 (2013).
35. R. G. Haight, D. T. Cleland, R. B. Hammer, V. C. Radeloff, T. S. Rupp, *J. For.* **102**, 41–48 (2004).
36. V. C. Radeloff *et al*., *Proc. Natl. Acad. Sci. U.S.A.* **115**, 3314–3319 (2018).
37. K. Rao, A. P. Williams, N. S. Diffenbaugh, M. Yebra, A. G. Konings, *Nat. Ecol. Evol.* **6**, 332–339 (2022).
38. S. Nazare, I. Leventon, R. Davis, "Ignitibility of structural wood products exposed to embers during wildland fires : a review of literature" (National Institute of Standards and Technology, NIST Technical Note NIST TN 2153, 2021); https://doi.org/10.6028/NIST.TN.2153.
39. C. A. Kolden, C. Henson, *Fire* **2**, 9 (2019).
40. J. K. Balch *et al*., *Remote Sens.* **12**, 3498 (2020).
41. L. Giglio, L. Boschetti, D. P. Roy, M. L. Humber, C. O. Justice, *Remote Sens. Environ.* **217**, 72–85 (2018).
42. S. Leyk, J. H. Uhl, *Sci. Data* **5**, 180175 (2018).
43. J. H. Uhl *et al*., *Earth Syst. Sci. Data* **13**, 119–153 (2021).
44. L. A. St. Denis *et al*., *Sci. Data* **10**, 112 (2023).
45. M. Goss *et al*., *Environ. Res. Lett.* **15**, 094016 (2020).
46. M. A. Moritz *et al*., *Ecosphere* **3**, art49 (2012).
47. S. L. Stephens *et al*., *Front. Ecol. Environ.* **12**, 115–122 (2014).
48. J. K. Balch *et al*., *Earth's Futur.* **8**, e2019EF001319 (2020).
49. M. C. Cook, "Drivers of wildfire-related home loss across the western United States 2001-2018," thesis, University of Colorado, Boulder, CO, USA (2021).
50. J. H. Scott, M. P. Thompson, D. E. Calkin, "A wildfire risk assessment framework for land and resource management" (US Department of Agriculture, Forest Service, Rocky Mountain Research Station, General Technical Report RMRS-GTR-315, 2013); https://www.fs.usda.gov/rm/pubs/rmrs_gtr315.pdf.
51. V. C. Radeloff *et al*., *Science* **382**, 702–707 (2023).
52. T. J. Cova, D. Li, L. K. Siebeneck, F. A. Drews, *Nat. Hazards Rev.* **22**, 06021003 (2021).
53. P. E. Dennison, T. J. Cova, M. A. Mortiz, *Nat. Hazards* **41**, 181–199 (2007).
54. E. Kuligowski, *Fire Saf. J.* **120**, 103129 (2021).
55. S. L. Quarles, K. Pohl, "Building a wildfire-resistant home: Codes and costs" (Headwaters Economics, 2018); https://headwaterseconomics.org/wildfire/homes-risk/building-costs-codes.
56. S. L. Quarles, C. Standohar-Alfano, F. Hedayati, D. J. Gorham, *Int. J. Wildland Fire* **32**, 380–387 (2023).
57. J. T. Abatzoglou, A. P. Williams, *Proc. Natl. Acad. Sci. U.S.A.* **113**, 11770–11775 (2016).
58. J. T. Abatzoglou *et al*., *Earths Future* **11**, e2022EF003471 (2023).
59. C. S. Juang *et al*., *Geophys. Res. Lett.* **49**, GL097131 (2022).
60. A. L. Mahood, J. K. Balch, *Ecosphere* **10**, e02591 (2019).
61. J. T. Abatzoglou, J. K. Balch, B. A. Bradley, C. A. Kolden, *Int. J. Wildland Fire* **27**, 377–386 (2018).
62. M. E. Cattau, C. Wessman, A. Mahood, J. K. Balch, *Glob. Ecol. Biogeogr.* **29**, 668–681 (2020).
63. K. Barrett, T. Preston, K. Pohl, P. Hernandez, "Wildfires destroy thousands of structures each year" (Headwaters Economics, 2020); https://headwaterseconomics.org/natural-hazards/structures-destroyed-by-wildfire/.
64. J. J. Stephens *et al*., "Fires of unusual size: future of extreme and emerging wildfires in a warming United States (2020-2060)" [Preprint] ESS Open Archive (2023); https://doi.org/10.22541/essoar.170224524.49212451/v1.
65. L. St. Denis *et al*., All-hazards dataset mined from the US National Incident Management System 1999-2020 [Preprint]. Figshare (2023); https://doi.org/10.6084/m9.figshare.19858927.v3.

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used in this analysis are publicly available. All code necessary to reproduce this analysis is available at https://github.com/viriglesias/fast-fires. The workflow to derive the linked ICS-209+ and FIRED product per (*44*) is available at https://github.com/maxwellCcook/ics209-plus-fired/blob/main/code/R/ics-fired.Rmd. The all-hazards dataset mined from the US National Incident Management System is hosted on Figshare (*65*). Fire Events Delineation (FIRED) CONUS-AK 2001-2022 data are available at https://scholar.colorado.edu/concern/datasets/d504rm74m and latest (version 2) are available at https://scholar.colorado.edu/concern/datasets/fx719p11c. The Historical Settlement Data Compilation of the US (HISDAC-US) data are available at: https://dataverse.harvard.edu/dataverse/hisdacus. US Environmental Protection Agency ecoregions are listed at https://www.epa.gov/eco-research/ecoregions. The Monitoring Trends in Burn Severity (MTBS) website is at https://www.mtbs.gov/.

SUPPLEMENTARY MATERIALS

science.org/doi/10.1126/science.adk5737
Materials and Methods
Supplementary Text
Figs. S1 to S8
Tables S1 to S8
References (*66*–*78*)

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10.1126/science.adk5737

COLLINS Eleni * ODF

From: Darlene Chirman <darlene.chirman@gmail.com>
Sent: Monday, January 20, 2025 1:03 PM
To: FORESTRY Boardof * ODF
Subject: Implement CCCP in Oregon State Forets
Attachments: BOF Implement the CCCP Broads comment letter 2025-1-20.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Board of Forestry—
Please accept the attached comment letter from the Great Old Broads for Wilderness, Cascaded-Volcanoes Chapter, as testimony following the presentation at the Board of Forestry meeting on January 9, 2025, the update on the implementation of the Climate Change and Carbon Plan.
Sincerely, Darlene Chirman
Leadership Team, Cascade-Volcanoes
Great Old Broads for Wilderness

Darlene Chirman
7017 SE Martins St
Portland OR 97206
805-455-3541

To: Chair Kelly, Members of the Oregon Board of Forestry
State Forester Mukumoto, State Forest Division Chief Michael Wilson
Email: BoardofForestry@oregon.gov
Date: 1/20/2025
RE: **Implementation of the Climate Change and Carbon Plan**

Dear Chair Kelly, Members of the Board of Forestry and State Forester Mukumoto:

I am submitting comments on behalf of the Great Old Broads for Wilderness, Cascade-Volcanoes chapter; we thank you for managing state forests for the greatest permanent value for all Oregonians. We appreciate that you are moving forward to finalize the Habitat Conservation Plan for Western Oregon State Forests (HCP), as the best means of complying with the mandatory requirements of the federal Endangered Species Act (ESA). We also appreciate the approval of the Climate Change and Carbon Plan (CCCP) in November 2021. In recent draft documents of the Forest Management Plan, the Adaptive Management Plan, and the Vision for Oregon's Forest, implementation of the CCCP is mentioned. We urge the Board of Forestry (BOF) and the Department of Forestry (ODF) to move forward with meaningful, measurable progress on the CCCP. I attended the Board of Forestry meeting virtually on January 9th, and was signed up to give verbal testimony on January 8th. I was unable to testify, as I couldn't locate the zoom link; I watched the presentation on the CCCP on YouTube. I notified the BOF staff, requesting that the link for testifying be displayed more prominently on the website and in the emails sent to speakers who have signed up to testify. Clearly others were able to find the link, as I heard their remote testimony on January 8th when I was registered to speak.

Carbon inventory of State Forests. I was pleased to learn that the Forest System Carbon Report, in partnership with the USFS using long-term plots, should be finished by the end of the year. Are there sufficient plots within state forests, to provide a baseline for comparison of habitat conservation areas and timber production stands over time? If not, we urge the ODF to establish another monitoring mechanism to provide this information. What is the frequency of the Forest System Carbon Report? Is it adequate for adaptive management for the state forests for increasing carbon storage and sequestration?

In previous decades of high levels of timber harvest, Oregon's state forests were carbon sources. Recent analyses are contradictory, showing the state forests as carbon sinks or carbon sources. For the time periods to 2030 and to 2050, we urge you to ensure the state forests are optimized as carbon sinks.

Carbon sequestration and storage targets. Former Governor Brown's Executive Order 20-04 directed the Oregon Global Warming Commission, now renamed the Oregon Climate Action Commission, to set state goals for carbon sequestration and storage by Oregon's natural and working lands, including forests, in coordination with the Departments of Forestry and Agriculture and the Oregon Watershed Enhancement Board. According to the CCCP:

> "The Department has worked with the Oregon Global Warming Commission (OGWC) to establish a goal for natural working lands (i.e., forests, agriculture, tidal wetlands, etc.) as outlined in Executive Order 20-04. **The OGWC recommendation is an additional 5 MMTCO2e can be sequestered on an annual basis by 2030 and an additional 9.5 MMTCO2e annually by 2050."**

We ask the BOF to set targets of the contribution of additional sequestration to these goals to be accomplished on state forests for the target dates of 2030 and 2050. What is the status of this work in the ODF? This was not mentioned in the board report on the CCCP.

HB3409 required the (now) Oregon Climate Action Commission to develop a natural and working lands net biological carbon sequestration and storage inventory, allowing for a public comment process. HB3409 set a deadline of 1/1/2025 for establishing biological carbon sequestration goals of Oregon's natural and working lands. The inventory must 1) Be based on the best available field-based and remote sensing data on biological carbon sequestration; 2) Be developed using methods consistent with methods used to assess greenhouse gas fluxes related to land use, land change and forestry for the United States Environmental Protection Agency's Inventory of U.S. Greenhouse Gas Emissions and Sinks. ODF must do its part to accurately provide that data. That deadline has passed, what has been the ODF contribution to this task?

The legislature provided $10,000,000 for natural working lands as natural climate solutions. How much of this Natural and Working Lands Fund was awarded to ODF, and how has it been used? There is possible legislation to provide ongoing funding at the $5 million level in the current session. For us to advocate for additional funding, we need to know the current status of the program.

Habitat Conservation Areas. There was mention at the Board of Forestry meeting that the habitat conservation areas will be storing and sequestering carbon, and "that's enough". While by design the HCA and RCA will retain and sequester more carbon over time, this can be enhanced by co-managing conservation areas for carbon mitigation. While the primary purpose of the conservation areas is for endangered species habitat, management actions such as silvicultural treatments should also be evaluated for their carbon impact as a secondary consideration.

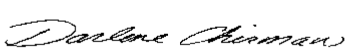
Climate Smart Forestry. The BOF and ODF have the most control of the state forests that you manage. To be a leader in climate smart forestry, you must incorporate climate smart actions in the management of timber production in state forests. The harvest scenarios modeled for the Forest Management Plan can help with this; it doesn't require choosing one scenario, but a mix of strategies such as rotational age, to maintain harvest volume while increasing the average age of the forest and at harvest. We wish to caution the DOF that simply harvesting older trees may actually reduce the average tree age when the goal is to *increase* the average age of production stands. You may choose to grow older trees adjacent to riparian buffers, with staggered harvests outside of the buffers. Increase tree retention in modified clearcuts, prioritizing older trees and snags. Consider biochar creation as alternative slash management, which adds stable soil carbon over long time spans. Climate mitigation is the core principle of climate smart forestry. What components of Climate Smart Forestry are being incorporated in the new Forest Management Plan?

Forest Carbon Finance and Markets. The CCCP discusses the possible implementation of a forest carbon offset market, if resources were available for its development. The BOF and ODF should explore carbon projects *within* the state forests. The development of a carbon project at the Elliott State Research Forest may serve as a model. These could be in areas of high risk—such as unstable slopes that can be logged, but might have higher risks of landslides and higher costs to harvest. An excellent carbon project area would be sites proposed for harvest within the Cook Creek Aquatic Anchor, or other areas where the sites are hard to access and thus costly to harvest.

Nationally, there are forest carbon offsets for biochar. As an alternative slash management technique, biochar can be created in portable forest kilns, where slash is burned in a low-oxygen environment to create a stable form of soil carbon. This can reduce greenhouse gas emissions and provide funding for the higher labor costs of this management technique. The BLM and USFS are piloting a project on Holiday Fire sites on BLM land, utilizing a CharBoss, to manage burned debris from the fire. This could be investigated for state forest harvest projects. While we advocate for natural recovery post-fire in conservation areas, in production stands, this could benefit carbon storage and help fund restoration post-fire.

Summary. The Great Old Broads for Wilderness asks the Board of Forestry and Department of Forestry to act with urgency to implement the Climate Change and Carbon Plan that was approved by the BOF over 3 years ago. There is increasing talk about CCCP implementation, but measurable baseline forest carbon inventory, measurable targets for increasing the carbon sequestration and storage on state forests are needed, and Climate Smart Forestry measures must be incorporated in the Forest Management Plan.

Sincerely,



Darlene Chirman
Darlene.chirman@gmail.com
Leadership Team, Cascade-Volcanoes Chapter
Great Old Broads for Wilderness

COLLINS Eleni * ODF

From: Josie Koehne <josephine.koehne@gmail.com>
Sent: Wednesday, January 08, 2025 7:39 AM
To: FORESTRY Boardof * ODF
Subject: How to implement climate smart forestry at low cost to the state
Attachments: Testimony on property tax special assessment rule changes 2.docx

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Testimony-Board-Mtg.

Chair Kelly and members of the Board of Forestry,

Attached are some thoughts on easy ways to get important forest management work done on fire mitigation and carbon sequestration at low cost to the state and taxpayers.

Thank you for this opportunity to offer this testimony.

Josie Koehne
Small forest owner
Gaston OR 97119

(503) 866-3346

Low Cost Climate Smart Forestry Implementation

My name is Josie Koehne and I am a small forestland owner with 80 acres in the eastern foothills of Coastal Range in Washington County. I am not representing any of the organizations I volunteer for with this testimony. I am just offering an idea for your consideration which I have discussed with a few other small woodland owners that reflects some of our mutual interests.

As a small forestland owner with highest and best use timber land, (HBU), we are entitled to the Western Oregon Forestland Program's special assessment which reduces the county property taxes we pay annually, so long as we manage the property primarily for growing and harvesting timber. Many small owners like ourselves would rather manage our land for wildlife habitat and for a better climate outlook for future generations, but not all woodland owners can qualify for the conservation special assessment from ODFW, *if* it's available in their county, nor for a permanent conservation easement which can be very hard for small forest owners to get due to complicated and costly legal requirements. For the forestland program special assessment, a forest management plan is required to meet timber stocking and species requirements, and to thin periodically for tree health and growth. To qualify for the small tract forestland (STF) program (which requires a 10-acre minimum), a forest plan is not required. But due to the few stewardship foresters available in each region and very few rural county assessors (there are 3 in Washington County), there is little follow up, if any, to ensure that the land is properly thinned and cleared of invasives and underbrush to prevent wildfire, and to ensure that timber is harvested as required. Small forest owners are required by law to harvest timber to qualify for the special assessment, although there may be few mills nearby of marketable species (7 mills closed this year and 700 jobs were lost). In addition, harvesting operations are costly, so often landowners let their trees go unmanaged even though they are getting a sizeable tax break.

Now that the state is trying to manage its forests under the extreme conditions caused by climate change and we know that we need to sequester more carbon in trees on a landscape scale, perhaps the rules need to be re-examined to allow for *not* harvesting trees for timber. In addition to carbon sequestration, ecological services, watershed protection, soil, noise and air pollution reduction, the benefits of living trees of all species, especially in mature and old growth forests is well-documented. As part of climate mitigation and adaptive management, growing a broad mix tree species and having longer timber harvest rotations are climate smart practices that should be encouraged if we are to reach our state and nation's GHG reduction goals.

Rule Change Proposal

To retain existing special assessments and for new landowners, forestland owners would need to work with the technical assistance of the local stewardship forester or the fire marshal's office to develop *either* a timber plan ***or a conservation plan*** for the duration of their ownership, to be monitored by the stewardship forester every five years or so. A 10-acre minimum should be required to qualify for the forestland program special assessment, not just 2 acres, and climate smart forestry practices, including thinning and brush removal, and creating wildfire defensible spaces around all buildings would be well-defined *and required* in order to keep the special assessment under a conservation plan. Timber species and stocking requirements would no longer be required. Instead, mixed species and habitat improvements for wildlife and to sequester carbon for the long term would be spelled out in the conservation plan.

Benefits of a Conservation Plan

There are nearly 4.7 million acres (about 44%) of prime Oregon forestland in small forest ownership (under 5000 acres), with the potential to sequester enormous amounts of carbon from the atmosphere.

- Requires very little additional funding resources
- Incentivizes climate smart forestry practices at no cost
- Allows small forest owners the *choice* of managing for timber harvest or for not harvesting
- Takes the pressure off those who feel they are legally obligated to harvest timber
- Reduced timber supply would increase market prices for large commercial timber producers, and should not negatively impact their operations
- Improves tree stand health and resistance to pests on a large scale
- Preserves canopy to reduce heat and protects microbes in soils and lessens soil compaction
- Reduces wildfire risk from ladder fuel build-up
- Managing properly for timber production, wildfire mitigation and for conservation purposes requires selective, non-commercial thinning for tree health and habitat improvements
- Commercial timber mills and operators have automated work processes (feller-bunchers, wood-handling/sawing machines, drones and conveyor systems, etc.) eliminating many lower-wage jobs
- Creates new job opportunities to meet the new conservation plan obligations for wildfire mitigation, requiring hand chain-saw work, slag pile clearing, chipping and biochar production, etc.
- Federal NRCS and other existing incentives for wildfire and brush clearing can be used by forest owners under a conservation plan
- The burden of proper forest management falls to the landowner receiving an existing tax special assessment, rather than to the state

Other Thoughts on Timber Taxes

Upon harvest, both public and private forest owners and operators pay the low Harvest Tax currently set this year at $6.30 per thousand board feet (MBF). In the two most recent ODF timber sales in my Forest Grove District, the price for Doug fir was $691.22/MBF fir. Prices have been as high as $1000 recently especially for cedar. To give you some idea of the low Harvest Tax, a large log truck can hold up to 5 MBF, that's $3,456 worth of harvested timber. At the this year's Harvest Tax rate of just under $6.30/MBF, Oregon gets back just $31.50 for that truckload of timber after years and years of reduced taxes while those trees were growing. And the first 25MBF are untaxed! Other timber severance taxes were gradually reduced in the late 90s and eliminated by 2003 except for the small STF program, yet the volume of harvest over the past decade remains at about 3.8 billion BF per year. Timber property taxes were kept low and remain low due to Measure 50. That leaves just the income tax. But with forestlands have increasingly converted to real estate investment trust tax status (REITS) and managed by a few timber management companies (TIMOs), Oregon and the federal government can collect ***<u>nothing</u>*** in income tax from timber that is sold primarily to stockholders who pay dividends in their own state while our trees are being harvested at a young age of 35 years to their maximize ROI. These large commercial for-profit owners still getting many tax credits. Large timber land owners and land managers need to once again pay a reasonable share of taxes comparable to other industries. We should replace the complicated Harvest Tax with a simpler timber severance tax as we once had, but one based on a combination of timber volume and value. Income taxpaying timber companies should get a deduction on their severance taxes. Severance tax revenues could be applied to wildfire resistance preparation and to replace revenue now paid to the FTLAC timber counties from state timber harvests.

COLLINS Eleni * ODF

From: Josie Koehne <josephine.koehne@gmail.com>
Sent: Thursday, January 09, 2025 11:45 AM
To: FORESTRY Boardof * ODF; MUKUMOTO Cal T * ODF
Subject: Updated ideas for implementing climate smart practices
Attachments: Testimony on property tax special assessment rule changes 2.docx

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Testimony-Board-Mtg.

Glad to hear Peter Hayes and Washington County stewardship foresters and others are working on to better define climate smart forestry. Perhaps that group should be consulted on best forestry practices for western forests.

New ideas have been added here to my previous doc.

Low Cost Climate Smart Forestry Implementation

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Now that the state is trying to manage its forests under the extreme conditions caused by climate change and we know that we need to sequester more carbon in trees on a landscape scale, perhaps the rules need to be re-examined to allow for *not* harvesting trees for timber. In addition to carbon sequestration, ecological services, watershed protection, soil, noise and air pollution reduction, the benefits of living trees of all species, especially in mature and old growth forests is well-documented. As part of climate mitigation and adaptive management, growing a broad mix tree species and having longer timber harvest rotations are climate smart practices that should be encouraged if we are to reach our state and nation's GHG reduction goals.

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- Improves tree stand health and resistance to pests on a large scale
- Preserves canopy to reduce heat and protects microbes in soils and lessens soil compaction
- Reduces wildfire risk from ladder fuel build-up
- Mixed forests, ie., heterogeneity of forest stands for both commercial and small private forestland OSU recommends as the best way to plan for mitigating wildfire intensity and severity
- Managing properly for timber production, wildfire mitigation and for conservation purposes requires selective, non-commercial thinning for tree health and habitat improvements
- Commercial timber mills and operators have automated work processes (feller-bunchers, wood-handling/sawing machines, drones and conveyor systems, etc.) eliminating many lower-wage jobs
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- The burden of proper forest management falls to the landowner receiving an existing tax special assessment, rather than to the state

Other Thoughts on Timber Taxes

Upon harvest, both public and private forest owners and operators pay the low Harvest Tax currently set this year at $6.30 per thousand board feet (MBF). In the two most recent ODF timber sales in my Forest Grove District, the price for Doug fir was $691.22/MBF fir. Prices have been as high as $1000 recently especially for cedar. To give you some idea of the low Harvest Tax, a large log truck can hold up to 5 MBF, that's $3,456 worth of harvested timber. At the this year's Harvest Tax rate of just under $6.30/MBF, Oregon gets back just $31.50 for that truckload of timber after years and years of reduced taxes while those trees were growing. And the first 25MBF are untaxed! Other timber severance taxes were gradually reduced in the late 90s and eliminated by 2003 except for the small STF program, yet the volume of harvest over the past decade remains at about 3.8 billion BF per year. Timber property taxes were kept low and remain low due to Measure 50. That leaves just the income tax. But with forestlands have increasingly converted to real estate investment trust tax status (REITS) and managed by a few timber management companies (TIMOs), Oregon and the federal government can collect ***nothing*** in income tax from timber that is sold primarily to stockholders who pay dividends in their own state while our trees are being harvested at a young age of 35 years to their maximize ROI. These large commercial for-profit owners still getting many tax credits. Large timber land owners and land managers need to once again pay a reasonable share of taxes comparable to other industries. We should replace the complicated Harvest Tax with a simpler timber severance tax as we once had, but one based on a combination of timber volume and value. Income taxpaying timber companies should get a deduction on their severance taxes. Severance tax revenues could be applied to wildfire resistance preparation and to replace revenue now paid to the FTLAC timber counties from state timber harvests.

Comments to the Oregon Board of Forestry
Meeting January 8 & 9, 2025
Climate Change and Carbon Plan (Climate Plan) and AOP Improvements

Ken Adee, Astoria Oregon
1/23/2025

Career Background: I worked for the US Forest Service for 35 years. For 7 years, I worked as a Research Forest Ecologist. The rest of my career with the USFS was in forest management planning, managing geographic information in support of resource management, and transforming business practices through technology innovations. I've worked in the forest and seen firsthand the impacts of both unsustainable and sustainable forest practices on Federal lands and State lands, but the worst impacts are on privately owned forests.

Appreciation for ODF's Efforts: I appreciate the positive achievements of the Oregon Board of Forestry and Oregon Department of Forestry, including moving forward with the state forest habitat conservation plan (HCP) and development of the Climate Change and Carbon Plan (Climate Plan).

Dominance of Corporate Forests: The forest industry is dominated by big corporate players, influencing forest management practices in the region. A substantial portion (65% to 90%) of private forestland in Western Oregon is controlled by large corporate entities. Over the past two decades, private forest ownership has shifted, now largely dominated by Real Estate Investment Trusts (REITs) and Timber Investment Management Organizations (TIMOs), collectively referred to as Wall Street forestry. Weyerhaeuser, a major forest products company, stands out as the largest REIT, and Hancock Timber Resource Group is the leading TIMO. Their primary goal is profitability for investors, which comes at the cost of ecological sustainability. The distinct change is not in the business form but in their tax-exempt status.

ODF Climate Plan's Focus: While the ODF Climate Plan primarily focuses on managing state forests, it also aims to influence practices on privately owned forests through collaborative efforts and incentives. This promotes a "shared stewardship" approach across the landscape, encouraging climate-smart forestry practices on both public and private forestlands. There is a double standard in the narrative surrounding timber production in Oregon, and it is vital to address corporate-controlled lands in forest management discussions.

Sustainable Forest Practices in the Climate Plan: The plan advocates for climate-smart forestry, managing forests to adapt to climate change while reducing greenhouse gas emissions and supporting forest-dependent communities. It includes implementing climate-informed silviculture, using alternative tree species, planting densities, and longer harvest rotations. Additionally, it emphasizes modernizing Oregon's wildfire protection system and developing fire-adapted communities. However, the plan falls short by omitting key sustainable practices.

Forest Conservation vs. Forest Preservation: On a larger scale, there is a need for both forest conservation and preservation:

- **Forest Conservation** focuses on sustainable use and management of forest resources, balancing human needs with ecosystem protection. Practices include sustainable harvesting, forest management, and restoration to maintain ecological functions while allowing resource use such as timber, non-timber products, and recreation.
- **Forest Preservation** aims to protect forests from human intervention, maintaining them in their natural, undisturbed state. The goal is to safeguard biodiversity and ecosystem integrity by setting aside areas where no resource extraction or development occurs.

Ecological Forest Management (EFM): Forest conservation in the ODF Climate Plan must be more robust. Ecological Forest Management (EFM) presents an integrative approach that balances conservation and economic goals. Implementing EFM principles addresses concerns related to taxation, job losses, ecological impacts, and lost production potential. Wall Street forestry views forests primarily as capital resources optimized for financial returns, which often disregards ecological considerations. EFM recommends against maximizing a single good or service (e.g., timber production) and emphasizes managing forests for multiple ecosystem services. This holistic approach promotes sustainable forestry that supports local economies without compromising forest health.

EFM is adaptive, tailoring strategies to various forests, goals, and regulatory frameworks. It emphasizes maintaining ecological integrity, protecting high-value ecological areas, and enhancing biodiversity. EFM challenges conventional silviculture that relies on clearcutting and monocultures, promoting instead an ecosystem-based approach that values ecological health, adaptability, and sustainability.

Biodiversity and Resilience in EFM: EFM leverages the natural variability of forest ecosystems, ensuring continuity and enhancing biodiversity and resilience. It suggests managing individual stands within the broader landscape context, fostering biodiversity, and facilitating the movement of organisms. EFM practices can aid in the restoration of threatened species and align with broader conservation goals, ensuring the integrity of ecosystems.

Adapting to Climate Change through EFM: EFM provides a holistic approach to forest conservation, emphasizing forest resilience in the face of climate change. Strategies for resilience include maintaining diversity, ensuring connectivity between ecosystems, and monitoring environmental changes. EFM also addresses the challenges of frequent-fire forests by establishing low-density, fire-resistant tree stands. EFM plays a role in carbon sequestration, maintaining healthy forests that capture and store carbon dioxide.

EFM's approach to harvesting is consistent with the goal of increasing carbon storage. It involves retaining more trees during harvest and adopting longer intervals between harvest operations. This approach leads to higher carbon retention and reduces the carbon debt that comes with clearcutting.

Supporting Rural Communities with EFM: Local communities play a critical role in EFM's success due to their deep connection to forests. They offer the workforce and local manufacturing capabilities required for forest management, creating an economic ecosystem. EFM emphasizes involving local populations in decision-making processes, providing various societal benefits, from job opportunities to the preservation of cherished forest values. This approach can stabilize local economies and deepen the bond between communities and their environment.

EFM is especially beneficial for small landowners, offering both ecological and economic advantages. Small landowners can selectively manage their forests, ensuring biodiversity while generating revenue. Incentives such as tax breaks, conservation easements, and carbon credits can further support landowners in adopting EFM practices.

Recommendations for Improving Forest Sustainability in Oregon:

- Ban the use of pesticides and herbicides on both state and private forests in all community watersheds and progress towards a ban on all forests.
- Change the taxing of forest harvesting to ensure they pay their fair share and increase revenue for county services.
- Increase rotation length to enhance timber production, ecosystem services, funding for county services and increase biodiversity and carbon storage, reducing soil degradation.
- Retain legacy components during harvest to maintain biodiversity and forest structure continuity.
- Incorporate traditional ecological knowledge, especially from Indigenous communities, in forest management practices.
- Integrate policies recognizing the value of younger forest stages and promote their management for biodiversity and ecological resilience.
- Invest in educational campaigns that highlight the ecological, cultural, and recreational significance of forests.

- Lengthening rotation cycles to.

Annual Operations Plan (AOP) Issues: There are issues with the lack of adequate notice and relevant information for the public regarding planned operations. Neighbors of planned operations are not notified before preliminary AOP approval, which undermines ODF's goal of providing the public with "meaningful opportunities to comment."

Recommendations for Improving the AOP Process:

- Increase awareness of the AOP process and extend the public comment period.
- Assist ODF in providing adequate survey information to the public ahead of time.
- Allow citizens to connect and engage with ODF staff ahead of preliminary approvals.
- Expand the limited 45-day public comment period.
- Hold public meetings in each district upon the release of the draft AOP.
- Encourage the development of local citizen advisory groups for input on State Forest management.

Closing Remarks: I thank the Board for considering my comments.

COLLINS Eleni * ODF

From:	Laura Wilkeson <LauraWilkeson@hamptonlumber.com>
Sent:	Wednesday, January 22, 2025 12:32 PM
To:	FORESTRY Boardof * ODF; KELLY Jim * ODF; MCCOMB Brenda * ODF; AGPAOA Liz * ODF; DEUMLING Ben * ODF; JUSTICE Joe * ODF; CURTISS Heath * ODF
Cc:	KUNERT dave
Subject:	Public Comments - Hampton Lumber
Attachments:	Jan Public Comments - Hampton Lumber.pdf
Follow Up Flag:	Flag for follow up
Flag Status:	Flagged

Chair Kelly and Board of Forestry Members,

Please see the attached comments from Dave Kunert on behalf of Hampton Lumber for the January Board of Forestry meeting.

Thank you.

Laura

Laura Wilkeson
Oregon Director of Government Affairs
Hampton Lumber
Cell: 971-304-4215
www.hamptonlumber.com

HAMPTON LUMBER

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Telephone 503.365.8400
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www.HamptonLumber.com

January 22, 2025

Submitted via: boardofforestry@odf.oregon.gov

Oregon Department of Forestry
2600 State Street
Salem, OR 97310

RE: January Board of Forestry Public Comments

Dear Chair Kelly and Board of Forestry Members:

Thank you for the opportunity to submit comments on behalf of Hampton Lumber. As you know, Hampton has been and will remain engaged on State Forest issues affecting our industry and the surrounding communities. To that end, we have a few concerns that warrant the Board of Forestry's (Board) attention and understanding.

Additional restrictions are not needed

The Oregon Department of Forestry (ODF) staff and the Board continue to develop a new Forest Management Plan (FMP) to accompany the anticipated federal approval of the proposed Habitat Conservation Plan (HCP) and have moved the draft FMP into the rulemaking process. Throughout this process and the development of performance measures for the plan, it will be paramount for the Board, staff, and public to remember the immense set-asides already required under the HCP.

Under the HCP, over half of the forest will be put into Habitat Conservation Areas (HCAs), with minimal active management and no management in riparian areas. This severely limits acres available for active timber management, a crucial part of achieving greatest permanent value (GPV) and a goal in the draft FMP. Of the remaining acres outside HCAs, non-management of riparian buffers will be coupled with additional restrictions for northern spotted owl, stay-ahead provisions, and green tree retention.

Given these restrictions, we ask that staff and the Board refrain from placing additional, unduly burdensome restrictions on the acres left available for active management.

The three-legged stool identified as GPV is already lopsided under the HCP, to the detriment of the agency's and the surrounding communities' social and economic objectives. Tipping that scale further would be ill-advised and unnecessary. Several Board members have indicated they do not want to see the forest further constrained, and we appreciate and agree with their assessment.

Revenue concerns

There are many reasons why active management on state forests is important to the health of the forest and surrounding communities. First, as you know, ODF timber sales generate direct revenue for counties, schools, taxing districts, and ODF.

These funds are also needed to support the other social and environmental goals of the agency. State forest managers are now two fiscal quarters behind on the timber sales proposed in the current Annual Operations Plans (AOP). As of today, ODF has offered less than 10 MMBF of the 188 MMBF planned in the FY25 AOPs. Some districts haven't offered a timber sale since last summer. This delay and the risk of lost volume will come at significant costs to ODF, beneficiaries, and local forest sector businesses. While timber sales and AOPs are not under the Board's jurisdiction, the financial health of the agency and the needs of the trust land counties certainly are, which is why we are bringing this issue to your attention.

The 2024 wildfire season put ODF's cash flow issues and the limitations of general fund dollars under a microscope. A resolution for how to address the revenue shortfalls created by the HCP has yet to be identified. With significant new environmental protections assured under the HCP, allowing further harvest restrictions on state forestlands now would be irresponsible. We urge you not to sanction such questionable financial decisions.

Forest Management Plan modeling

When FMP modeling scenarios are released, I encourage ODF and the Board to consider these options in the context of the forest sector's abilities, needs, and limitations. Please understand that longer rotation ages or other goals that would defer or delay timber harvests will do further harm to local businesses and the communities that depend on reliable annual timber sales. You are aware that sawmills in our region have spent the last 30 years retooling operations to process a smaller log profile. ODF already harvests on a longer rotation than the majority of private timberland managers in the region. Manufacturers are unlikely to have the capacity to retool again nor the faith to make such significant investments given the lack of accountability inherent in the current system.

ODF and the Board must stay abreast of the needs and limitations of local milling infrastructure before making changes to the products you offer. We are happy to participate in conversations to ensure everyone understands the potential outcomes of management changes.

Thank you again for the opportunity to share our concerns. We remain available to discuss these or any other topics as needed.

Sincerely,

Dave Kunert
Vice President of Resources

COLLINS Eleni * ODF

From:	Michael Lilly <mjlilly@mac.com>
Sent:	Wednesday, January 08, 2025 12:00 PM
To:	FORESTRY Boardof * ODF
Subject:	Climate change and the Forest Management Plan
Follow Up Flag:	Follow up
Flag Status:	Flagged
Categories:	Testimony-Board-Mtg.

Dear Board Members:
My family and I together own 56 acres of forested land in Tillamook County. As a citizen and owner of forested property, I urge the Board to take a more active role in managing Oregon's State Forests in a manner that addresses the climate change problem. I am disappointed that to date, not enough has been done to realize the potential of the Climate Change Carbon Plan. I believe that ODF needs to fully integrate the Climate Change Carbon Plan into the Forest Management Plan.

A good step toward climate smart forestry would be to simply grow trees longer by harvesting on a longer rotation. Only about 5% of Oregon's state forests are over 100 years old, so the state forests provide ODF with an excellent opportunity to make climate smart forestry a reality.

In order to keep track of progress towards its goals, ODF needs to establish a baseline of existing carbon stored in the state's forests, and track measurements of changes so that progress in achieving climate smart forestry can be tracked. We all need to be sure that we are making progress. Measurements are the only way to do that.

I understand that ODF has been allocated over three million dollars from the Natural and Working Lands Fund to advance climate smart forestry. An excellent use of those funds would be to assign two staff members to focus their efforts entirely on bringing the Climate Change Carbon Plan into action.

Thank you for your attention.

Michael J. Lilly
8490 SW Cecilia Terrace
Portland, OR 97223
mjlilly@mac.com
503-752-2515

From:	Paulette Wittwer <wittwers@comcast.net>
Sent:	Tuesday, January 14, 2025 5:10 PM
To:	FORESTRY Boardof * ODF
Subject:	Letter to Forestry Board
Follow Up Flag:	Follow up
Flag Status:	Flagged

January 14, 2025

To: Oregon Board of Forestry

I am writing with my concerns about climate change and the need to make sure that Oregon's forests can be a way to mitigate carbon, not add to it. The state Climate Change Carbon Plan has yet to become part of the state Forest Management Plan This needs to be addressed. For example, our state forests are a tremendous climate resource; ODF could adopt policy to grow trees longer so they would more adequately store carbon.

The Department of Forestry needs to track their carbon plan, starting with a baseline and monitoring the positive changes in carbon storage. ODF has received a grant to support climate smart forestry and could use some of that to add staff that would focus on these critical developments.

I am a 5th generation Oregonian, a woodlands owner and an active conservationist.

Sincerely,
Paulette Wittwer
Portland, Oregon
wittwers@comcast.net

COLLINS Eleni * ODF

From:	Rhonda Piasecki <coyotevibe@yahoo.com>
Sent:	Thursday, January 09, 2025 9:49 AM
To:	FORESTRY Boardof * ODF
Cc:	anna Kaufman
Subject:	Public Testimony for 1/9/25
Follow Up Flag:	Follow up
Flag Status:	Flagged
Categories:	Testimony-Board-Mtg.

Good Morning Members of the Board, I'm Rhonda Piasecki, a north coast resident and I signed up but wasn't called upon to testify today. I'm very concerned about the numerous log trucks carrying old growth trees, and clearcut scars on hillsides that have increased annually. There have also been confimed sightings of cougars on haystack rock, wolverines in Nehalem and bobcats in backyards, all of which are symptoms of habitat destruction.

Why is clearcutting, pesticide spraying, and monocrop planting allowed despite scientific evidence of their harm to watersheds, our drinking water for 1/2 million people on the coast, the salmon, wildlife, and forests that attract thousands of tourists and generate over half a billion dollars annually? These logging practices should be updated to follow science and more sustainable practices.

🌲 Clear cutting is not only visually unappealing but also obliterates entire habitats, as well as significantly impacting water sheds.

🌲 The use of pesticides to eliminate "weed" trees pose a threat to streams, groundwater, and oceans, as well as shellfish. These so called "weed" trees support the growth of other trees through symbiotic relationships and contribute to forest diversity and health.

🌲 Monocultural tree farms are quickly replacing diverse forests that contain old growth and legacy forests. These forests are crucial in protecting endangered species, resisting forest fires, absorbing carbon, and preserving cultural heritage for indigenous communities. Preserving these forests is essential for the planet's health and future generations.

OSF Forest Management Plan and the Climate Change and Carbon Plan must prioritize sustainable forest harvesting practices that minimize environmental impact to our forests and watersheds, and to preserve all old growth forests. I'm asking that ODF also ensure open communication between ODF, landowners and individuals affected by logging.

To relieve the financial pressures on ODF, a possible solution could be to apply a severance tax to all lumber companies who do business here in Oregon.

Thank you for your attention.

COLLINS Eleni * ODF

From: Scott Killops <scott.killops@gmail.com>
Sent: Tuesday, January 21, 2025 4:02 PM
To: FORESTRY Boardof * ODF
Cc: Scott Killops
Subject: Public Comment for BOF Meeting Held 1/9/2025 - Re CCCP Implementation Update
Attachments: 20250109-bof-public-comment-cccp-presentation-scott-killops.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Hi BOF,

Attached is a public comment regarding the CCCP Implementation Update presented at the BOF meeting held on 1/9/2025.

Thanks,
Scott Killops
350PDX Forest Defense Team Member

To: Oregon Board of Forestry and Department of Forestry

From: Scott Killops

Subject: Public Comment for the Board of Forestry Meeting on January 9, 2025
Regarding the *Climate Change and Carbon Plan Implementation Update*

Date: January 9, 2025

Below is a written transcript of the live testimony I presented at the *Board of Forestry (Board) meeting on January 9, 2025*. In a chat with Board member Ben Deumling during a meeting break, he suggested that I also resubmit the *written testimony* I prepared regarding the *Climate Change and Carbon Plan Implementation Update* that was presented at the Board Retreat in October 2024. I have included that testimony as an attachment.

Chair Kelly, State Forester Mukumoto, and Members of the Board,

Thank you for your service and for the opportunity to provide a public comment today. For the record, my name is Scott Killops. I am a retired Software Program Manager and a volunteer team member with the 350PDX Forest Defense Team. My comment today regards the *Climate Change and Carbon Plan (CCCP) Implementation Update*.

At the last Board meeting I submitted *detailed written comments* regarding the *Climate Change and Carbon Plan Implementation Update* that was presented at the Board Retreat in October. The main message in those comments was that ODF does not appear to be actively managing CCCP implementation as a program. There appears to be no detailed implementation plan, no program manager, no cross-functional implementation team, no sponsor on the ODF Executive Team, and no tracking or oversight of CCCP implementation. The Board's CCCP implementation review in October was the first in the three years since the CCCP was approved. As a consequence, there appears to be little progress, especially in the area of forest carbon accounting.

The *Oregon Climate Action Commission Natural & Working Lands Fund Biennial Report* published in December 2024 includes seven actions that ODF plans to complete in 2025 (Section VI.C on page 15). However, none of these actions is stated in a measurable way. I recommend that ODF translate these actions into measurable deliverables and then create a work plan with assigned resources and a schedule to complete them. I further recommend that the ODF Executive Team review progress on this work plan on at least a quarterly basis.

Thank you again for your service and for the opportunity to provide a public comment today.

Respectfully,
Scott Killops
350PDX Forest Defense Team Member

Attachment: Public Comment for the Board of Forestry Meeting on 11/22/2024
Regarding the *CCCP Implementation Update to the BOF, 10/17/2024*

To: Oregon Board of Forestry and Department of Forestry

From: Scott Killops

Subject: Public Comment for the Board of Forestry Meeting on 11/22/2024
Regarding the *CCCP Implementation Update to the BOF, 10/17/2024*

Date: 11/16/2024

Thank you for the opportunity to provide public comments for the Board of Forestry (Board) meeting on 11/22/2024. My comments pertain to the *Climate Change and Carbon Plan (CCCP) Implementation Update* presented to the Board at their retreat on October 17, 2024. Since public comments were not accepted at the Board retreat, I'm providing my comments on the CCCP Implementation Update now.

I would like to preface my comments by sharing my background. I am a retired Software Program Manager with twenty years of experience managing large software development programs at Intel Corporation. As a consequence, I view both the *CCCP* itself and the *CCCP Implementation Update* through a program management lens. Observations and opinions expressed here are also biased by the Intel corporate culture in which I gained my program management experience. I am very much expressing a particular point of view. That point of view is limited by seeing only what the Board and ODF share on their web site and in their public meetings, so there is a certain amount of speculation in these comments.

I would also like to preface my comments by saying that they are intended as constructive input, not criticism. My hope is that these comments may contribute to the successful implementation of the CCCP. I have great respect for the Board and ODF and great appreciation for the hard work that you perform on behalf of all Oregonians.

Respectfully,
Scott Killops
350PDX Forest Defense Team Member

Thank you for your leadership on climate smart forestry.

I want to start by thanking the Board and ODF for your leadership on climate smart forestry. Thank you for creating and approving the *Climate Change and Carbon Plan (CCCP)* and for making Climate Leadership a priority in the *Vision for Oregon's Forests (Vision)*. Thank you also for creating and approving the *Western Oregon State Forests Habitat Conservation Plan (HCP)*. The Habitat Conservation Areas (HCAs) prescribed in the HCP should also serve as effective carbon stores. I also appreciate the many areas of progress reported by Forest Resources Director Josh Barnard in the *CCCP Implementation Update*. However, I do have concerns regarding how CCCP implementation is being tracked, about the implementation of the Forestry Natural Climate Solutions Fund, and about the lack of visible progress with ODF's Forest Carbon Accounting Framework. These concerns are discussed below.

Is CCCP implementation managed as a program at ODF?

From the outside, it appears that there is no CCCP implementation plan. Such a plan would define measurable outcomes and/or deliverables for each CCCP goal, a work breakdown structure or task list for the work to achieve these outcomes, the resource requirements to complete the work, a schedule for completing the work, and metrics by which progress will be tracked. Without an implementation plan, it's hard to say whether adequate resources are being requested or applied to achieve CCCP goals.

In the CCCP Implementation Update, Board member Bob Van Dyk asked State Forester Cal Mukumoto where we are with program funding. Cal replied that a Policy Option Package (POP) approved for the Governor's Request Budget (GRB) includes funding for John Tokarczyk's and Danny Norlander's positions. That's great news. But from a program management point of view, the answer should be based on a roll-up of the resource requirements in an implementation plan and whether those resources are available. If there are resource gaps, the impact of these gaps on ODF's ability to achieve CCCP goals should be articulated.

From the *Oregon Climate Action Commission (OCAC) Natural & Working Lands Fund (NWLF) Annual Report, September 2024*, it appears that there is a CCCP resource gap. In 2024 the NWFL allocated $3,250,000 to the ODF Forestry Natural Climate Solutions Fund to fund three projects. For all three of these projects the report states, "Due to staff capacity limitations and other delays, ODF will likely not be able to implement this project within the agency's originally proposed timeframe. ODF will likely request future expenditure limitation approval to extend project implementation into the coming biennium." However, the *2025-27 Biennium: Agency Request Budget (ARB)* doesn't even mention the CCCP nor any staffing limitations associated with it. Nor do any of the *POPs presented to the Board at the June 6 2024 BOF meeting*.

I am concerned that many CCCP Supporting Actions or dependencies are also under-funded. These include the Enhanced Forest Inventory system, the Forest Carbon Accounting Framework, and Research and Monitoring. Without an implementation plan or a more detailed CCCP Implementation Update, it's hard to say. But there has not been much visible progress in these areas since CCCP approval in November 2021. In particular, the CCCP states (page 40) that ODF intends to "Continue to produce the *Oregon Forest Ecosystem Carbon Inventory Report* on a biennial basis." To my knowledge, this report has not been produced since 2019.

I am fully aware that the coming biennium will be a difficult budget cycle and that ODF does not expect to get much, if any, additional funding from the legislature. However, this makes it more important to be clear about what can and cannot be accomplished with available resources and to set expectations with the Board and the public accordingly.

From the outside, it also appears that there is no CCCP implementation team. In my experience, a program as complex as the CCCP requires a dedicated program manager leading a cross-functional team of representatives from the groups performing the work in order to achieve it goals. This team initially creates the implementation plan, then meets regularly to coordinate work, track progress and report metrics, manage issues and risks, and provide input to program updates. Using team input, the program manager provides written progress reports to ODF management on a regular basis. During the "Department Strategic Planning" discussion at the Board retreat, State Forester Cal Mukumoto said that he is trying to get ODF to work more cross-functionally, across organizational silos. Cross-functional implementation teams for complex programs like the CCCP are one good way to do this.

From the outside, it also appears that there is no sponsor or champion for the CCCP on the ODF Executive Team. Who is accountable for or cares deeply about the success of the CCCP? This person would ensure that an implementation plan for the CCCP is created, would seek adequate funding in biennial budgets, would monitor internal progress reports from the implementation team, would assist with removing barriers, and would ensure that a program update is presented to the Board on at least an annual basis. This does not seem to be occurring.

In summary, from the outside it looks like CCCP implementation is not being managed as a program. It looks like the CCCP is viewed as an aspirational document to which ODF managers are expected to align their operations, but with little coordination, oversight, or accountability. I think that ODF would achieve greater success with CCCP implementation if they did manage it as a program. If ODF does not manage CCCP implementation as a program, I think that the ODF Executive Team should make a bigger commitment to looking for CCCP alignment and progress in division operation reviews and status reports.

CCCP Implementation Update

The *CCCP Implementation Update* presentation was largely comprised of slides from the *Climate Change and Carbon Plan informational webinar held on May 27, 2021*. Most of this presentation material was devoted to the history of the creation of the CCCP and a brief overview of CCCP contents. Just four slides were devoted to the CCCP Implementation Update per se.

(Slide numbers below refer to slide numbers in *20241017-bof-meeting-materials.pdf*, since there are not slide numbers on the CCCP Implementation Update slides themselves.)

Slide #45 – Forest Resources Update: This slide was a place-holder for Forest Resources Director Josh Barnard's verbal update on activities in his division which support the CCCP. This was a great update, the most detailed of the presentation. But as several Board members commented, it would be good to have it in writing and good to have similar updates from the other ODF divisions. The State Forests division has a *Draft Western State Forests Management Plan* out for review and will *soon begin the process of updating district Implementation Plans for FY2026-27*. It would be good to get an update on how they intend to use these plan revisions to advance the climate smart forestry goals of the CCCP.

Slide #46 – How Are We Doing?: This slide is the CCCP Implementation Update in a nutshell. This slide might have been a good intro or overview if it were followed by more detailed implementation update slides. Unfortunately, it wasn't. This slide states, "A wide variety of unforeseen changes have made some goals and actions unachievable or difficult," but it doesn't say which goals are now unachievable. It also states, "Tracking not there" with sub-bullets stating that this is due to "Vision interaction" and "Vision metrics". It's not clear to me why work on the *Vision for Oregon's Forests (Vision)* should interfere with tracking implementation of the CCCP, unless the same ODF resource is assigned to both activities. Even then, the workload seems manageable.

Slides #36-43 – CCCP Goals: These slides were not presented in the Board retreat, but were included in the posted meeting material. These slides are taken from the CCCP webinar and present one goal per slide with the CCCP statement of the goal. Since the CCCP was approved three years ago, what would be more useful is one goal per slide with actions completed since 2021, actions planned to be completed in the coming biennium (i.e. the upcoming budget cycle), an update on any barriers affecting this goal, and an assessment of whether goal achievement is on track or not.

Slide #30 – Barriers – The CCCP (pages 11-12) includes a table of "Potential Barriers" and "Resolutions or means to address issues". The "Barriers" slide is just a high level summary of the kinds of barriers included in the CCCP. Three years into CCCP implementation, it would have been more useful to describe actions that have been taken to address barriers, which barriers remain, what actions are planned to address remaining barriers, and what help is needed to address remaining barriers.

Slide #44 – Supporting Actions – The CCCP devotes 11 pages to defining 14 Supporting Actions of which it says, "Supporting actions are linked to multiple Goals. Depending on the action, impacts can and will extend to several goals, they are not limited to a one-to-one goal relationship. These supporting actions will be incorporated into agency planning, which includes documents and processes like Board Work Plans, Forest Management Plan, Implementation Plans, and Annual Operating Plans, among others." The CCCP Implementation Update devotes one slide to Supporting Actions with no status update. Three years into CCCP implementation, it would have been more useful to describe actions that have been taken to date and actions that are planned to be completed in the coming biennium.

Slide #47 – Where are we going?: This slide states that CCCP metrics work stopped when Vision for Oregon's Forests work began, but it doesn't say why. It's not clear to me that these activities need to be coupled, especially since the Vision rolls up the CCCP goals as strategies and the Board decided not to insist on measurable goals in the Vision. In the same BOF meeting in which the CCCP was approved on November 3, 2021, there was an agenda item titled *2021 Board of Forestry State Forests Metrics Update* (pages 188-199). This update included draft carbon storage metrics for Oregon State Forests. I see no reason why this work should not continue other than resource constraints, which is why I am concerned about CCCP resource requests in the current *ODF ARB* and *associated POPs*.

This slide makes no mention of the *OCAC Draft Natural & Working Lands Fund Biennial Report – 2024 Report to the Oregon Legislature*. This report includes a Section VI, Actions Planned for 2025, with a Subsection C for ODF which lists seven actions. These actions would have been good to include here.

Slide #48 – Other Active Climate Change Efforts: This slide is a useful overview, but it's not followed by any more detailed slides. It would be good to add a slide for each of ODF's key collaborations regarding the CCCP. These should include at least the OCAC for work on the Natural & Working Lands Fund and the USFS for work on forest inventory and forest carbon accounting.

Oregon Climate Action Commission – Natural & Working Lands Fund

ODF is collaborating with the *Oregon Climate Action Commission (OCAC)* on implementation of *HB3409 (2023) Sections 53-67, State Policy for Natural Climate Solutions*. This includes implementation and allocation of the Natural & Working Lands Fund (NWLF) and the Forestry Natural Climate Solutions Fund (FNCSF). This is a major new development since the CCCP was approved and should have warranted a more detailed discussion in the CCCP Implementation Update.

The *Oregon Climate Action Commission (OCAC) Natural & Working Lands Fund (NWLF) Annual Report, September 2024* indicates that in 2024 the NWLF allocated $3,250,000 to fund three ODF projects:

Project No.	Agency	Program / Project	Fund Allocation
P9	ODF	Advance Implementation of Climate-Smart Forestry	$1,500,000
P10	ODF	Climate-Smart Forestry: Tribal and EJ Partnerships	$1,000,000
P11	ODF	Establishment of Climate-Ready Seed Orchards	$750,000

For all three of these projects the report states, "Due to staff capacity limitations and other delays, ODF will likely not be able to implement this project within the agency's originally proposed timeframe. ODF will likely request future expenditure limitation approval to extend project implementation into the coming biennium." It would be good to get an update on whether the staff capacity limitations and other delays have been resolved.

The *OCAC Draft Natural & Working Lands Fund Biennial Report – 2024 Report to the Oregon Legislature* includes a Section VI, Actions Planned for 2025, with a Subsection C for ODF which lists seven actions:

- Provide funding to local districts to increase adoption of climate-smart forestry activities through incentives and technical assistance for existing programs.
- Provide funding to tribes that want to implement climate-smart forestry practices on tribal

forest lands.
- Work on implementation of ODF's climate-ready seed efforts to provide species and seed that are more climate adapted as informed by future projections.
- Continue implementing associated ODF efforts, such as the Climate-Smart Forestry Award; supporting long-lived wood fiber utilization (e.g., mass timber); and administering forest health treatments to increase resistance, increase adaptation, or direct the forest ecosystem dependent on the local conditions.
- Track and work to secure national and international climate and carbon-related funding through grants and other opportunities.
- Continue efforts around the adoption of a Habitat Conservation Plan (HCP) and a Forest Management Plan for State Forests, and an HCP for private riparian areas, which include climate considerations.
- Continue research projects and efforts that will inform interests in carbon stocks and cycles, land use issues related to forestry, and the effects of climate on insects, diseases, and abiotic factors.

These actions are not stated in a measurable way. Without a CCCP implementation plan as discussed above, it's hard to say what ODF's deliverables are for 2025.

The *OCAC Draft Natural & Working Lands Fund Biennial Report – 2024 Report to the Oregon Legislature* includes a Section III, "Other State, Federal, and Private Funding Sources" with a Subsection C, "Pending and Planned Funding Requests". For ODF, this Subsection states: "Advance Implementation of Climate-Smart Forestry (ODF): ODF anticipates that N&WL funds will enable cooperators to leverage additional federal resources to support climate-smart forestry practices. No funds have been leveraged to date, but efforts are underway to identify potential funding sources." Two years following passage of the Inflation Reduction Act (IRA) and three years following passage of the Infrastructure Investment and Jobs Act (IIJA), ODF should be able to speak with more specificity about federal funds they are pursuing. The Board meeting on September 7, 2022 included a presentation on *Inflation Reduction Act and Bipartisan Infrastructure Investment and Jobs Act funding for America's Forests*. ODF should leverage this presentation to create a more detailed report.

It should be noted that the *Urban and Community Forest (UCF) Program Update for 2024* reports that UCF applied for, and was awarded, over $27M in Federal grants through the IIJA and IRA. It's not clear why this is not included in the NWLF biennial report. (It should also be noted that the UCF program update is a good example of a written program update that the CCCP program may want to emulate in the future.)

The *OCAC Draft Natural & Working Lands Fund Biennial Report – 2024 Report to the Oregon Legislature* also includes a Section VII, "Looking Forward: Natural Climate Solutions Investment Potential" with the description, "The following subsections describe the potential and need for additional investments in natural climate solutions identified by ODA, ODFW, and OWEB." There is a footnote stating, "The

Oregon Department of Forestry declined to provide content for this section." This seems like a missed opportunity.

Forest Carbon Accounting Framework

The CCCP Implementation Update did not discuss ODF's forest carbon accounting framework at all. But the CCCP devotes two pages (under Supporting Actions – Monitoring and Research) discussing plans in this area. This includes a plan to produce the *Oregon Forest Ecosystem Carbon Inventory Report (FECR)* on a biennial basis. To my knowledge the FECR has not been produced since its initial release in 2019. In fact, it appears that the ODF *Forest Carbon Accounting* web page has not been updated since 2019. It looks like there hasn't been a Board update on forest carbon accounting since the *State Forests Carbon and Inventory* report in September 2022. Forest carbon accounting is foundational to managing forests for carbon sequestration and storage. It appears that ODF and the Board should devote more attention to this area.

Three years after the approval of the CCCP, the *Stand Level Inventory (SLI) Annual Report 2024* doesn't even include the word carbon. I think ODF should make it their ambition to include a carbon inventory in this annual report. Three years ago ODF created draft carbon storage performance measures that included per-district trend graphs (see State Forests Performance Measure Update, November 3, 2021, in *20211103-bof-agenda.pdf* pages 188-199 and in *20211103-bof-presentations.pdf* slides 97-119). I think that ODF should adopt these carbon storage performance measures and include per-district trend graphs in the creation of district Implementation Plans, Annual Operations Plans, and Annual Reports.

According to the USFS *Forest inventory and Analysis (FIA)* web site, "The Forest Inventory and Analysis (FIA) program published a *new modeling system in September 2023 for predicting tree cubic-foot volume, biomass, and carbon attributes*, completing a goal of the 2015 FIA Strategic Plan. This system, termed 'National Scale Volume and Biomass Estimators' (NSVB), provides a more consistent and accurate accounting of structural components of trees across the US for total tree cubic-foot volume, biomass, and carbon." It would be good to get an update on whether ODF intends to adopt the NSVB.

Climate Change and Forest Carbon Work Plan 2022-2024

The Board Work Plan *Climate Change and Forest Carbon Work Plan 2022-2024* was not addressed in the CCCP Implementation Update. Board member Bob Van Dyk brought it up and asked about the status of the Framework for Climate Change Assessment, which has not been implemented. But this work plan includes five work items and it would be good to get a progress report for each of them:

Topic A: Climate Change and Carbon Plan Tracking
Topic B: Framework for Climate Change Assessment
Topic C: American Forests – Carbon & Climate Change Modeling

Topic D: Participation in the Temperate Forest MOU and Work with the USFS PNW Research Station on Forest Carbon Co-Production efforts
Topic E: Estimation of the Department Greenhouse Gas footprint

References

BOF and ODF References

ODF web page – Climate change
https://www.oregon.gov/odf/forestbenefits/pages/climate-change.aspx

ODF web page – Forest carbon accounting
https://www.oregon.gov/odf/forestbenefits/Pages/forestcarbonstudy.aspx

ODF Climate Change and Carbon Plan
https://www.oregon.gov/odf/forestbenefits/Documents/odf-climate-change-and-carbon-plan-draft.pdf

BOF Climate Change and Forest Carbon Work Plan 2022-2024
https://www.oregon.gov/odf/board/bof/bofwp-climate-change-2022-2024.pdf

Legislative Reference

Oregon House Bill 3409 (2023) – See Sections 53-67, State Policy for Natural Climate Solutions
https://olis.oregonlegislature.gov/liz/2023R1/Downloads/MeasureDocument/HB3409/Enrolled

Oregon Climate Action Commission (OCAC) References

Oregon Climate Action Commission
https://climate.oregon.gov/

Draft Natural & Working Lands Fund Biennial Report - 2024 Report to the Oregon Legislature
https://static1.squarespace.com/static/59c554e0f09ca40655ea6eb0/t/670da47945543015558591dd/1728947322202/2024-DRAFT-OCAC-NWL-Fund-Biennial-Report.pdf

Natural & Working Lands Fund Annual Report – September 2024
https://static1.squarespace.com/static/59c554e0f09ca40655ea6eb0/t/66df4041690d12650cb7e0fc/1725907018175/2024-OCAC-NWL-Fund-Annual-Report.pdf

Natural & Working Lands Fund Proposal – January 2024
https://static1.squarespace.com/static/59c554e0f09ca40655ea6eb0/t/6594aea62498db70a925d691/1704242854973/2024-NWL-Joint-Proposal.pdf

United States Forest Service (USFS) References

Forest Inventory and Analysis
https://research.fs.usda.gov/programs/fia

Tree Volume, Biomass, and Carbon Models
https://www.fs.usda.gov/research/programs/fia/nsvb

Pacific Northwest Research Station - Carbon Research Initiative Update, 2022
https://research.fs.usda.gov/sites/default/files/2023-02/pnw-cibr-2022-final.pdf

Board of Forestry Meeting Presentations Related to the CCCP

10/17/2024 – Climate Change and Carbon Plan Implementation Update (pages 17-49)
https://www.oregon.gov/odf/board/bof/20241017-bof-meeting-materials.pdf

9/4/2024 – Urban and Community Forestry Program Update for 2024
https://www.oregon.gov/odf/board/bof/20240904-bof-item-e.pdf

9/4/2024 - 2024 Climate Smart Forestry Award Recognition
https://www.oregon.gov/odf/board/bof/20240904-bof-item-9.pdf
https://www.oregon.gov/odf/board/bof/20240904-bof-record-item-09.pdf

3/8/2023 – Sightline Institute: Long Rotational Forestry Discussion
https://www.oregon.gov/odf/board/bof/20230308-bof-item-06.pdf
https://www.oregon.gov/odf/board/bof/20230308-bof-record-item-06.pdf

3/8/2023 – Climate Smart Award (pages 54-63)
https://www.oregon.gov/odf/board/bof/20230308-bof-packet.pdf
https://www.oregon.gov/odf/board/bof/20230308-bof-record-item-03.pdf

11/16/2022 – Our Search for Climate-Smarter Forestry: Accelerating the Transition (pages 172-197)
https://www.oregon.gov/odf/board/bof/20221116-bof-packet.pdf

9/7/2022 – State Forests Carbon and Inventory
https://www.oregon.gov/odf/board/bof/20220907-bof-item-07.pdf
https://www.oregon.gov/odf/board/bof/20220907-bof-record-item-7.pdf

9/7/2022 - Inflation Reduction Act and Bipartisan Infrastructure Investment and Jobs Act (pages 1-9) and Stages for Implementing Forest Carbon Plans and Policies (pages 10-18)
https://www.oregon.gov/odf/board/bof/20220907-bof-record-item-9.pdf

6/8/2022 - Carbon Trends on Oregon State Forests (pages 1-3),
Pacific Coast Forest Carbon: Estimating Regional Carbon Stocks and Flux (pages 89-130),
Memorandum of Understanding - Pacific Coast Temperate Forests (pages 132-133),
DLCD – Overview: Oregon's Land Use Planning Program (pages 134-143),

DLCD – Climate Change Resilience Assessment (pages 144-155)
https://www.oregon.gov/odf/board/bof/20220608-bof-handouts.pdf

6/8/2022 - Oregon Forest Ecosystem Carbon Inventory: 2001 – 2016 (pages 63 – 73)
https://www.oregon.gov/odf/board/bof/20220608-bof-agenda.pdf

11/3/2021 - Climate Change and Carbon Plan Final Draft Approval (pages 334-402)
https://www.oregon.gov/odf/board/bof/20211103-bof-agenda.pdf

11/3/2021 – State Forests Performance Measure Update (pages 188-199)
https://www.oregon.gov/odf/board/bof/20211103-bof-agenda.pdf

9/8/2021 – Governor Kate Brown's Executive Order 20-04 (pages 173-186)
https://www.oregon.gov/odf/board/bof/20210908-bof-agenda.pdf

9/8/2021 - Summary of Comments Received on Climate Change and Carbon Plan (pages 189-191)
https://www.oregon.gov/odf/board/bof/20210908-bof-agenda.pdf

11/4/2020 – Oregon Forest Carbon Accounting Framework (pages 148-151)
https://www.oregon.gov/odf/board/bof/20201104-bof-agenda.pdf
Oregon Forest Carbon Accounting Framework (pages 64-183)
https://www.oregon.gov/odf/board/bof/20201104-bof-handouts.pdf

11/4/2020
Board of Forestry Authority to Address Issues Related to Climate Change (pages 19-48)
https://www.oregon.gov/odf/board/bof/20201104-bof-handouts.pdf

COLLINS Eleni * ODF

From: Stacey Detwiler <sdetwiler@wildsalmoncenter.org>
Sent: Thursday, January 09, 2025 4:25 PM
To: FORESTRY Boardof * ODF
Subject: Public Comments, BOF meeting 1/8/25
Attachments: 1_8_25 Written Comments BOF Meeting.pdf

Follow Up Flag: Follow up
Flag Status: Flagged

Categories: Testimony-Board-Mtg.

Hi Eleni,

Please see the attached public comments for the January 8, 2025 BOF meeting.

Thanks,

Stacey

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Stacey Detwiler

Oregon Policy Director

Wild Salmon Center

2001 NW 19th Avenue, Suite 200
Portland, OR 97209

Pronouns: she/hers

Office: 971-255-5583 (does not receive text messages)

Chair Jim Kelly
Oregon Board of Forestry

January 9, 2025

RE: Public Comments on Private Forest Accord Rule Implementation and Habitat Conservation Plan Budget Needs for 2025-2027 Biennium

Chair Kelly, Board Members, and State Forester Mukumoto:

Thank you for the opportunity to provide public comments into the record. The Wild Salmon Center is a nonprofit organization based in Oregon that works to protect and restore healthy forests and abundant clean water to support thriving wild salmon populations in the state and across the Pacific Rim. The Wild Salmon Center is one of the Private Forest Accord Authors as part of the conservation coalition and has engaged in this process from the beginning in 2020. Stacey Detwiler currently serves as the co-chair of the Adaptive Management Program Committee, but these comments are on behalf of the Wild Salmon Center and do not represent the committee.

First, we'd like to thank Board Member Bob Van Dyk for his service on the Board, particularly to his commitment to accountability, transparency, and community engagement on issues before the Board and facing Oregon's forests and communities. Second, we would like to provide more detailed comments regarding the funding needs for three programs that are critical to ensuring a federally approved Private Forest Accord Habitat Conservation Plan (HCP). Third, we would like to highlight the importance of resources and support to ODF and ODFW to finalize the stream flow permanence model and the fish use survey protocol that are critical for PFA rule implementation and PFA HCP development in the upcoming year.

The Private Forest Accord: 2020 - 2024

As we head into 2025, it's important to acknowledge the nearly five years of intensive negotiations, rule drafting and implementation, and HCP development by the PFA Authors and agency staff at ODF and ODFW. In February 2020, the original Memorandum of Understanding (MOU) was signed between 13 conservation groups and 13 timber companies that kicked off what became known as the Private Forest Accord. Negotiations concluded in October 2021, followed by landmark bipartisan legislation authorizing the agreements under SB 1501 in March

2022, which was then signed into law by Governor Brown in May 2022. New rules implementing the changes were drafted and approved in October 2022 and the full suite of new rules went into effect as of January 1, 2024. The first round of grants under the PFA Grants Program at ODFW were awarded in May 2024 and the first round of small forestland owner grants under the SFISH Program at ODF were awarded in August 2024. The state submitted the first comprehensive draft of the PFA HCP to NOAA and USFWS in July 2024, and received initial feedback from those federal agencies in December 2024.

The Private Forest Accord in 2025: Funding Needs in the 2025-2027 State Budget

One of the most critical actions for the success of the PFA and ensuring a federally approved PFA HCP by 2027 will be for the state to fully fund core programs at ODF and ODFW for the 2025-2027 biennium. Three programs for a total of $36M, specifically 1) the PFA Grant Program at ODFW, 2) the small forestland owner SFISH Grant Program at ODF, and 3) the Adaptive Management Program at ODF, were not included in the base budget or in the Agency Request Budgets (ARBs). These programs are foundational to securing an HCP and represent commitments in the authorizing legislation SB 1501.

The Governor's Recommended Budget released on December 2nd appears to significantly underfund these core programs and commitments in the PFA authorizing legislation (SB 1501).

- **PFA Grant Program at ODFW:** This program provides dedicated grant funding for fish passage barrier removal, stream habitat restoration, and other mitigation projects. The PFA authorizing legislation (SB 1501) commits $10M from the state and $2.5M from industry annually for this fund until federal approval of an HCP, after which the industry contribution increases to $5M annually. For the state, this represents a legislative commitment of $20M per biennium. These long-term investments are core components of the negotiated agreements under the PFA authorized in SB 1501 and updated rules, as well as the HCP. Currently, under the GRB – this program is funded at $10M for the biennium, which is half of the total $20M needed.

- **Small forestland owner SFISH Grant Program at ODF:** This program provides grants to small forestland owners to replace or upgrade culverts and stream crossings. Ongoing investment in this program is a core component of the PFA's new requirements to provide increased technical and financial assistance to small forestland owners, particularly as the new rules are now in effect. Underfunding this program will limit the technical and financial assistance available to small forestland owners as the new rules are implemented. This program is funded at $4M in the GRB; however, the total need for this program is $10M for the biennium.

- **Adaptive Management Program at ODF:** The Adaptive Management Program, which is a linchpin of the agreement and the mechanism through which the state and the Services determine the effectiveness of the new rules for meeting biological objectives for the covered species, appears to not currently be funded at all under the GRB. Budget shortfalls will make it challenging to conduct needed research and meet standards of an approvable HCP, as well as recruiting and retaining qualified experts for the Adaptive Management Program Committee (AMPC) and the Independent Research and Science Team (IRST). The total need for this program in the biennium is $6M.

The following table summarizes the best available information for funding levels in the GRB for these three programs. We continue to work with the Governor's Office to better understanding funding levels for these programs.

Table 1. Summary of 2025-2027 Funding Needs and Current Funding Levels in the GRB for Critical PFA Programs

	2025-2027 Funding Need	**2025-2027 Funding in GRB**
PFA Mitigation Grant Program - ODFW	$20M need (SB 1501 appropriated $10M to ODFW for the Mitigation Program in 2022 and the remaining $10M was included in an ODFW POP in the 2023-2025 budget.) Legislative commitment in SB 1501 for state to commit $10M/year for PFA Grant program and timber industry contribution of $2.5M/year. After federal approval of HCP, industry contribution increases to $5M/year	$10M in GRB
SFISH Program (ODF)	$10M need (Funded at $6.67M in 23-25)	$4M in GRB
Adaptive Management Program (ODF)	$6M need (Funded at $4M in 23-25)	$0 in GRB

These programs at ODF and ODFW are not currently included in the base budget, but they are foundational to the success of the HCP and ensuring federal approval. Through the Private Forest Accord, the state moved out of decades of gridlock around logging on private forest lands. We can't afford to go back to fights at the ballot box, expensive lawsuits, and painstaking progress to protect healthy forests and clean water. We thank the Board for your support for the PFA process and ask that you support full funding for these programs in this critical window of time before 2027 to shore up efforts for federal approval.

Additional Work Related to PFA Rule Implementation and PFA HCP Development in 2025

In addition to funding critical programs in the 2025-2027 biennium, we would like to highlight two additional work areas that are critical to successful implementation of the new rules and an approvable HCP.

1. **Support and resources to finalize the Stream Flow Permanence Model by July 2025:** The PFA made important changes to management along small non-fish (Type N) streams, and identifying where those streams transition from perennially flowing to seasonally flowing is integral to successful implementation of the new rules. ODFW has been leading efforts in close coordination with ODF to develop a comprehensive statewide high-resolution stream network and a stream flow permanence model that will identify end of flow permanence on small type N streams. Until that modeling work is completed, landowners and agencies will continue to rely on field surveys to identify the end of flow permanence. In 2025, it will be critical to ensure that there are resources and support for both ODFW and ODF to finalize this flow permanence model and move this process into the Phase 2 regulatory model approach.

2. **Support and resources to finalize the Fish Use Survey Protocol in 2025:** The "Surveying Forest Streams for Fish Use" protocol draft was developed by ODFW and ODF and is integral to effective implementation of the OFPA and the new rules established under the PFA. Major rules related to riparian buffers, steep slopes, and roads all tie back to the classification of streams as fish (Type F) or non-fish (Type N). The PFA made important changes to how this classification is developed and implemented, including in requirements to develop a new fish use protocol that will replace the 1995 procedures. It is critical that this protocol is comprehensively reviewed and that substantive edits from stakeholders are integrated into a final product that can be implemented. Both ODFW and ODF need the staff, resources, and support to ensure that this protocol is finalized and implemented.

Thank you for the opportunity to provide more detailed comments regarding the PFA budget needs for the 2025-2027 biennium and additional work in 2025 related to PFA implementation and PFA HCP development.

Sincerely,

Stacey Detwiler
Oregon Policy Director
Wild Salmon Center