NATIONAL WILDFIRE ALLIANCE · nationalwildfirealliance.org

Suppression Firing

Counting the acres burned on purpose

The unmeasured variable in American fire science: what is known, what is not, what it costs us, and what the agencies can do about it now

National Wildfire Alliance – Research for Transparency in Government

Author: Frank Carroll, Vice President, National Wildfire Alliance September 21, 2026

Summary

American wildland firefighters deliberately ignite fire inside wildfire perimeters as a routine tactic. The practice is required by doctrine, taught in a national curriculum, equipped with an expanding arsenal of aerial delivery systems, and conducted at a scale nobody counts. The acres it burns enter the national wildfire statistics without a label. The fire it produces is not distinguished from free-spreading fire in any dataset researchers use. Its effects on soils, old trees, water, air, and listed species have never been measured against a control, in any fuel type, anywhere.

This is not a contested claim. The Forest Service published it in its own proceedings eleven years ago: "There has been no systematic tracking of suppression firing locations, so the size or severity of these fires individually or cumulatively is currently unknown." The peer-reviewed literature repeats the finding about the United States and cites that Forest Service source. The one American team that tried to reconstruct firing operations on a single fire concluded the archival record was insufficient and that they had to interview the people who lit the fire.

Nine findings anchor this review.

One. The scale is unknown and is not small. In Victoria, Australia, the only jurisdiction that has systematically quantified the practice, suppression firing accounted for a mean of 29 percent and a median of 24 percent of final fire area on the fires where it could be mapped, ranged from under 1 hectare to about 20,000 hectares, reached 94 percent on one fire, and ran along 19 percent of the total external perimeter of 74 large fires. Nothing comparable has been attempted here.

Two. The national archive records firefighter ignition as a line with no width, and the record is thin in a way that is itself evidence. Queried directly for this review, the National Incident Feature Service annual archives yield, for 2022 through 2025, 1,128 distinct Completed Burnout line features carrying 36,955,362 feet of recorded length against 106,406 distinct completed fireline features of all types carrying 1,994,573,745 feet. Burnout is **1.85 percent of recorded completed fireline length and 1.06 percent of features.** In 2024, only 105 of the 988 incidents with any mapped fireline carried any mapped burnout at all, and in 2025 only 109 of 1,865. Roughly one incident in ten, falling to one in seventeen.

Set that against doctrine. The NWCG definition of indirect attack states that "The intervening fuel is usually backfired." The agency tactics guide states that "A line not burned out is almost worthless." Either burnout is vastly rarer than doctrine describes, or it is systematically not mapped. Given that no written firing plan is required on a wildfire and no standard requires any record of acres ignited, the second explanation is far more likely. **The national geospatial record of firefighter ignition is not merely incomplete. It is thin enough to be misleading.**

Three. Burnout has no area anywhere in the federal record. Completed Burnout exists as an Event Line feature under NWCG geospatial standards and does not exist as a polygon. The 2024 Event Polygon layer admits two category values, Wildfire Daily Fire Perimeter and Prescribed Fire, and a burnout query returns zero. Line width, the one attribute that would convert fired line to acres, is populated on 11 of 2,061 archived burnout rows in 2024 and 17 of 733 in 2023. The United States records where it puts fire on the ground and has built no capacity to convert that record into area.

Four. Aerial ignition is the delivery method that makes this a landscape-scale act, and it is growing fast. Forest Service unmanned aircraft ignition treated 128,913 acres in fiscal 2023 and 188,986 acres in fiscal 2024, a 47 percent increase, while spheres dropped rose from 322,246 to 733,115, a 127 percent increase. Aerial ignition flight hours went from roughly 140 in fiscal 2022 to more than 251 in fiscal 2023 to approximately 855 in fiscal 2024. Helicopter gelled gasoline delivered on helitorch missions rose from 2,846 gallons in calendar 2021 to 6,070 gallons in calendar 2022. Dispensing capability rose from 30 spheres per minute in 2019 to 120 by 2022 with a fourfold payload increase, and the Department of the Interior holds a blanket purchase agreement with the dominant vendor carrying a 10-million-dollar ceiling through May 2028.

Five. Reporting resolution fell as the activity grew. The U.S. Department of Interior's fiscal 2022 interagency report published aerial ignition as a named mission category with 602 flights, 12 percent of all interagency drone flights. Fiscal 2023 named it and gave no count. Fiscal 2024, covering 7,833 flights and a 27 percent increase, dropped the category. The most recent national figures the Forest Service has published, approximately 758 aerial ignition hours and 134,381 acres treated by drone ignition, appear in a May 2026 feature article **with no year attached.** They match no published annual report; they are not fiscal 2022, 2023, or 2024, all of which were checked. The fiscal 2025 report has not been released.

Six. A burnout inside a wildfire requires no written plan. A prescribed fire requires an approved 21-element burn plan, a separately signed agency administrator ignition authorization, a Go/No-Go checklist signed by a qualified burn boss, and documented compliance with the National Environmental Policy Act, the National Historic Preservation Act, and the Endangered Species Act. The NWCG firing operations curriculum states that on a wildfire the firing plan "may be dynamic and informal plan generated within a short time frame," that the decision to backfire sits at division supervisor level, and that the decision to burn out is "typically made at the single resource boss level." Both quotations were verified verbatim for this review against the 2014 student workbook.

Seven. Four regulatory asymmetries follow from that, and together they are the heart of the problem. The same fuel, lit by the same person, with the same torch, on the same ground, is governed by four different regimes depending on whether a burn plan exists. Under the federal Exceptional Events Rule, smoke from a prescribed fire must be shown to have been unpreventable under a certified smoke management plan, while smoke from fuel ignited inside a wildfire is wildfire smoke and carries no such burden. Resource protection for listed species, cultural sites, riparian buffers, and old growth is a required planning element for prescribed fire and is advisory on an incident, delivered through a Resource Advisor whose assignment is discretionary and whose authority is to advise. Prescribed fire requires monitoring and recording of fire behavior, smoke, and first-order fire effects; suppression firing requires none. And retardant dropped to hold the line that burnout is fired from carries a mandatory 300-foot waterway buffer and a duty to report every misapplication to the wildlife agencies, while the fire lit off that line carries neither.

Eight. The effects have essentially not been studied. Two peer-reviewed case studies exist on the fire effects of drone ignition, both since 2023, both uncontrolled, both prescribed fire. No study compares aerially ignited fire to naturally spreading fire. No study examines helicopter plastic sphere dispenser or helitorch ignition effects across

four decades of the practice. No emissions inventory distinguishes ignition source. No field measurement anywhere pairs fuel consumption inside a mapped burnout with a free-burn control on the same fire. Across six resource domains reviewed here, searches of the research literature returned no study in which ignition source appears as a predictor, a stratum, or a covariate.

Nine. What this review does not claim. The proposition that intentional ignition burns the ground more completely than free-spreading fire is mechanistically coherent, doctrinally intended, and untested. The one American study that mapped firing operations and modeled their effect found that offensive firing reduced composite burn index by 40 to 49 percent inside prior fire footprints and that emergency defensive firing raised it by 1 percent. That study measured a canopy-weighted index, not ground consumption, so it does not settle the question. It does mean that anyone asserting the strong form of the claim is asserting past the evidence. This review names the proposition, states the mechanism, and specifies the experiment that would resolve it.

What follows from all of this is not an accusation. It is a work list. Most of the fixes are cheap. One of them is a data standard amendment that a subcommittee could make in a single meeting. Another is a summarize operation on a federal dataset that has already been published. A third is restoring a line item that an annual report carried two years ago and then dropped. The federal fire services do not need permission or new authority to start counting. They need to decide to.

Part 1. The practice, the authority, and the record it leaves

What it is

Three definitions from the NWCG Glossary of Wildland Fire carry the doctrine. All three were confirmed directly against the glossary for this review, with their status and steward committee.

> ***Burning out**, Approved, Incident Operations Subcommittee: "Setting fire inside a control line to consume fuel located between the edge of the fire and the control line."*
>
> ***Backfire**, Approved, Fuels Management Subcommittee: "A fire set along the inner edge of a fireline to consume the fuel in the path of a wildfire or change the direction of force of the fire's convection column."*
>
> ***Suppression firing**, **Archived**, Incident Operations Subcommittee: "Intentional application of fire to speed up or strengthen fire suppression action on wildfires. Types of suppression firing include burning out, counter firing, and strip burning."*

The verb in the first two is consume. Consumption of the intervening fuel is the stated purpose, not a side effect.

The third carries a status finding worth stating plainly. The only umbrella term NWCG has for the practice as a category is **Archived**, while the narrower operational terms remain Approved. The interagency body retired the name for the activity while the activity expanded.

The approved definition of **backfiring** adds a point that matters for accountability, and it comes from NWCG rather than from any critic:

> *"A tactic associated with indirect attack, intentionally setting fire to fuels inside the control line to slow, knock down, or contain a rapidly spreading fire. Backfiring provides a wide defense perimeter and may be*

> *further employed to change the force of the convection column. Backfiring makes possible a strategy of locating control lines at places where the fire can be fought on the firefighter's terms. Except for rare circumstance meeting specified criteria, backfiring is executed on a command decision made through line channels of authority."*

Why it happens at scale

The doctrinal authority is the definition of indirect attack, and it is blunter than most policy discussion admits:

> *"A method of suppression in which the control line is located some considerable distance away from the fire's active edge. Generally done in the case of a fast-spreading or high-intensity fire and to utilize natural or constructed firebreaks or fuel breaks and favorable breaks in the topography.* ***The intervening fuel is usually backfired;*** *but occasionally the main fire is allowed to burn to the line, depending on conditions."*

Combine "some considerable distance away" with "the intervening fuel is usually backfired," and large-scale intentional burning follows from published doctrine with no policy innovation required. The 1996 Wildland Fire Suppression Tactics Reference Guide states the operational view: "Burnouts are a must in the Southwest. A line not burned out is almost worthless. Burnouts are very successful at night as long as RH stays low."

Three developments enlarged the practice.

The 2009 policy change. The Guidance for Implementation of Federal Wildland Fire Management Policy, February 13, 2009, eliminated Wildland Fire Use as a distinct category and established at page 7 that "A wildland fire may be concurrently managed for one or more objectives and objectives can change as the fire spreads across the landscape." Page 10 directs agencies to "use planned and unplanned ignitions to achieve land and resource management goals." The 2003 Healthy Forests implementation strategy had constrained each wildland fire to a single management objective. That constraint fell. Forest Service Manual 5130, Amendment 5100-2020-1, effective August 18, 2020, codified the 2009 language nearly verbatim.

Potential Operational Delineations. PODs supply pre-season spatial boundaries scored against quantitative risk. The designers' own paper lists operational uses including "POD boundaries to strategically locate indirect and contingency lines" and "tactical firing operations to secure these features." The step from analytical planning boundary to ignition boundary is documented in the source paper, not alleged from outside. The Rocky Mountain Research Station published its own caution, a paper titled POD Boundaries and Fuel Breaks are not Synonymous, warning against exactly that conflation. No published study evaluates POD-boundary-based containment against ecological or property outcomes.

Aerial delivery. Treated in Part 2.

Authority, approval, and the planning asymmetry

This is the most consequential structural finding in the review, and it is entirely documentary. The quotations below were verified verbatim for this review against the primary sources.

A prescribed fire requires, under the Interagency Prescribed Fire Planning and Implementation Procedures Guide and the Red Book: a written, approved burn plan with 21 required elements including an ignition plan, a holding plan, a contingency plan, smoke management, monitoring, and post-burn activities; a signature page; an agency administrator ignition authorization signed separately from the plan; a Go/No-Go checklist signed by a qualified burn boss; and documented compliance with three statutes. The governing guide states it in one sentence:

> *"Prior to implementing prescribed fire under the standards in the PMS 484, local units must have ensured compliance with National Environmental Policy Act (NEPA), National Historical Preservation Act (NHPA) and Endangered Species Act (ESA) requirements."*

The Red Book assigns the signature duties:

> *"Sign and date the Agency Administrator Ignition Authorization (PMS 484-1, element 2A) with the time frame identified before the prescribed fire is ignited."*

> *"The USWFS will sign the Ignition Authorization for all prescribed fires. An NWCG qualified burn boss will sign the Go/No-Go Checklist."*

A burnout inside a wildfire requires, under the NWCG firing operations curriculum, the following. These four sentences appear in Unit 3 of the 2014 student workbook, the first two at page 3.12 under the printed heading "Basic Elements of a Firing Plan," and each was independently extracted twice for this review:

> *"Every firing operation requires a firing plan. On a RX fire this will be part of the written burn plan."*

> *"On a wildfire this may be dynamic and informal plan generated within a short time frame."*

> *"The decision to backfire is made at the division supervisor level or above."*

> *"The decision to burnout is typically made at the single resource boss level."*

The second sentence is reproduced exactly as printed, including the missing article before "dynamic." No written plan. No prescription window. No signed Go/No-Go. No agency administrator authorization. No statutory compliance documentation. Burnout authority at single resource boss level.

The curriculum is candid about the stakes. From the risk management unit: "One thing a Firing Boss should always remember is, once firing is initiated it can be very difficult to 'put the genie back in the bottle.'"

The same asymmetry appears in aerial ignition. NWCG Standards for Aerial Ignition, as published before its October 2025 revision, provided:

> *"For prescribed fire operations, only a FIRB, a Type 1 Burn Boss (RXB1) or Type 2 Burn Boss (RXB2) may direct UAS aerial ignition operations.* ***For a wildfire, a FIRB, RXB1, RXB2, Division Supervisor (DIVS), or Operations Section Chief (OSC) may direct UAS aerial ignition operations.****"*

Five qualifications may direct aerial ignition on a wildfire; three may on a prescribed fire. The wildfire threshold is lower for the same act, with the same equipment, in the same fuel. The October 2025 revision moved unmanned aircraft ignition content out of the aerial ignition standard and replaced it with a reference to the unmanned aircraft systems standard, so the current location of this provision should be confirmed before it is quoted in a formal submission.

One further loose end is worth naming. The unmanned aircraft systems standard instructs the pilot to "Conduct aerial ignition operations in accordance with approved aerial firing plans." The aerial ignition standard does not define or require such a plan. One standard directs compliance with a document the governing standard never mandates.

What the National Wildfire Coordinating Group ‘Red Book’ does and does not say

The Red Book was examined chapter by chapter for this review. The finding is an absence, and it should be stated in its narrow form.

Chapter 1 on federal policy and doctrine, Chapter 7 on safety and risk management, and Chapter 11 on incident management and response contain no provision on firing, burning out, backfiring, or aerial ignition. Chapter 16 on aviation operations delegates the entire subject in one sentence: "The NWCG Standards for Aerial Ignition (PMS 501) is policy for all aerial ignition activities." Chapter 17 on fuels management delegates prescribed fire to its planning guide.

No chapter examined imposes a firing plan requirement, a go/no-go requirement, a documentation requirement, or a resource protection requirement for firing operations conducted during wildfire suppression. Because the chapter-level files served publicly are a 2023 edition while the current combined edition is dated May 2026, and because automated extraction of a document that large is imperfect, the claim should be framed as stated here rather than as a claim that the Red Book never mentions firing.

The record it leaves

Because no plan is required, no plan is retained. Because no acreage field exists, no acreage is recorded. The records that do exist are short-lived. Under the National Archives approved Forest Service fire records schedule, the Individual Fire Report and the Incident History File are permanent and transfer to the National Archives after 20 years, while Incident Administrative Records, the category holding Incident Action Plans, briefings and checklists, are temporary and destroyed seven years after cutoff. There is no national archive of Incident Action Plans.

And in practice those plans say nothing. In a publicly released Incident Action Plan from a large 2020 fire, the division assignment sheets for four separate divisions are identical boilerplate: task, "Continue to patrol and secure fire edge within the division"; purpose, "Establish and hold containment lines to keep fire from reaching Values at Risk." Burning out, firing, backfire and aerial ignition appear nowhere in the document.

Part 2. Aerial ignition and the drone

Aerial ignition is what makes suppression firing a landscape-scale act rather than a line-scale one. The NWCG firing curriculum states it directly: "Aerial ignition is a good tool for burning large areas interior of firelines." Unmanned aircraft are the growth edge of that capability, and they are the least documented part of it.

The technology

Plastic Sphere Dispenser. The approved NWCG definition: "Device installed, but jettisonable, in a helicopter, which injects glycol into a plastic sphere containing potassium permanganate, which is then expelled from the machine and aircraft. This produces an exothermic reaction resulting in ignition of fuels on the ground for prescribed or wildland fire applications." The glossary also carries a companion entry for Delayed Aerial Ignition Devices that describes the spatial control directly: "The space between ignition points on the ground is primarily a function of helicopter speed, gear ratio of the dispenser, and the number of chutes used (up to four)." Ignition follows injection by roughly 20 to 30 seconds, longer in cold. The Premo Mark III dispenses at 45 to 130 spheres per minute. A single control area may store up to 250 pounds of potassium permanganate, about 35,000 spheres.

Helitorch. The approved definition: "An aerial ignition device hung from or mounted on a helicopter to disperse ignited lumps of gelled gasoline. Used for backfires, burnouts, or prescribed burns." The Simplex Model 5400 carries 55 gallons at a gross weight of 636 pounds, driven by a 28-volt, 2.4 horsepower motor through a positive displacement pump with manual flow control. At 200 feet and 40 miles per hour it "will produce particles the size of golf balls and burn approximately 8 to 10 minutes." Eight helitorch systems remain approved in the current aerial ignition standard, with new purchases of one model no longer authorized. Forest Service technology and development notes that gelled fuel makes helitorch "effective in larger forest fuels and marginal conditions," but that it "is not suitable for underburning due to gelled fuel sticking to tree crowns."

No agency document publishes a helitorch flow rate in gallons per minute. Every manufacturer manual and standard consulted for this review specifies only that flow is set by a manual valve. A frequently repeated figure, that the torch "will burn up to 200 acres per hour at a fuel consumption rate of 1.5 to 3 U.S. gallons," carries no time unit in its source and should not be converted into a rate.

Drone ignition. The dominant federal system is classified by NWCG as an approved plastic sphere dispenser rather than a separate device class. The capability curve is in the manufacturer's own datasheets:

Year	Recommended load	Drop rate
2019	110 spheres	up to 30 per minute
2022, heavy-lift platform	450 spheres	10 to 120 per minute

Roughly fourfold growth in both payload and dispensing rate in three years. The current systems carry up to 450 spheres, drop at up to two per second, reload in two to five minutes, and fly 22 to 30 minutes fully loaded, with a radiometric thermal camera and a full high-definition visual camera with 20x optical zoom. Federal platforms include the DJI Matrice 600 Pro, which logged 2,249 flights in fiscal 2024 as Interior's single most-flown aircraft type, plus two Freefly® airframes.

Documented ignition densities span a wide range. One operator reports that "1 sphere per 4 acres to 1 sphere per 2 acres was sufficient." A peer-reviewed operational study reports 7.8 spheres per hectare. That is roughly a thirtyfold range in ignition density, and no research establishes where within it fire behavior changes regime.

Standards

The NWCG Standards for Aerial Ignition, maintained by the Interagency Aerial Ignition Unit, require a written aviation safety plan submitted to the regional aviation manager, a pre-mission briefing covering communications, hazards, mitigations, aircraft performance and emergency procedures, a Go/No-Go briefing checklist, position task book completion, annual refresher training, and for helitorch a maintenance log and use record.

They require no record of ignition pattern, spacing, spheres dispensed, gallons of gel consumed, or acres intentionally burned.

Interagency approval of unmanned aircraft ignition payloads came under an interim memorandum in 2019 with full approval in February 2020. The Forest Service maintains a National UAS Aerial Ignition Specialist position, an aerial ignition academy, and a currency standard of three hours of aerial ignition flight time within the preceding twelve months.

The October 2025 revision of the aerial ignition standard made three changes relevant here. Unmanned aircraft ignition content was removed and replaced with a cross-reference. A new chapter on device malfunctions and

emergency procedures was established. And one approved plastic sphere dispenser, the Aerostat Mark V, is directed to be removed from service by 2027. That last item is the clearest documented restriction anywhere in the aerial ignition space, and it concerns equipment rather than practice.

Scale and trend

The adoption history is documented and is not a smooth curve.

- **2015.** Interior's Office of Aviation Services initiated a search for unmanned alternatives. The stated motivation is the agency's own casualty figure: since 2005, "two helicopters and five people have been lost in aerial ignition accidents."
- **April 2016.** First proof of concept ignition mission, a joint Interior, National Park Service and university team, on a 26-acre unit in Nebraska.
- **Fiscal 2018.** Interior reports the "first-ever drone based aerial ignition capability, including the first-ever night aerial ignition," with the payload "flown 177 times for more than 50 hours."
- **October 2019 to October 2022.** Interior grounded nonemergency drone flights. The Government Accountability Office records that bureaus "shifted to other methods, such as helicopters, for some aerial ignition operations," and that Interior drone flights had not returned to 2019 levels as of fiscal 2023. The curve regressed to crewed helicopter ignition for three years.
- **Fiscal 2022.** Interagency drone flights by mission: training and proficiency 2,685, or 51 percent; monitoring and inspection 1,094, or 21 percent; mapping 754, or 14 percent; **aerial ignition 602, or 12 percent**; research and testing 60; sampling 33. Total 5,228 flights and 1,031 flight hours.

The Forest Service unmanned aircraft annual reports carry the only clean time series of aerial ignition activity in the federal record, and it is a steep one.

Fiscal year	Aerial ignition hours	Imagery and video hours	Acres treated by drone ignition	Spheres dropped
2022	nearly 140	nearly 360	not reported	not reported
2023	more than 251	over 706	128,913	322,246
2024	approximately 855	over 1,304	188,986	733,115
Undated, reported May 2026	approximately 758	more than 1,400	134,381	not reported

Acres treated by drone ignition rose 47 percent from fiscal 2023 to fiscal 2024. Spheres dropped rose 127 percent. Aerial ignition hours rose roughly sixfold from fiscal 2022 to fiscal 2024.

The final row is a problem. Those national figures were published in a Forest Service feature article on May 21, 2026, with no fiscal year, calendar year, or period attached. They match no published annual report, and they are demonstrably not fiscal 2022, 2023, or 2024. The fiscal 2025 report has not been released. The largest set of national aerial ignition numbers in public circulation cannot be dated from its own source.

On the crewed side, the only published measure of helitorch activity is gelled gasoline delivered, and it appears in exactly two Forest Service aviation annual reports:

Calendar year	Gelled gasoline delivered on helitorch aerial ignition missions
2021	2,846 gallons
2022	6,070 gallons

A 2.1-fold increase in one year. No aviation annual report after calendar 2022 has been published, and earlier reports do not carry the metric, so there is no long series. No agency document quantifies a decline in helitorch use, and no agency document gives a count of units in service.

Procurement corroborates the trajectory. The Department of the Interior holds a blanket purchase agreement with the dominant drone ignition vendor, signed May 19, 2023, running to May 18, 2028, with a base and options value of 10 million dollars. Federal spending records show 21,953,857 dollars across 186 transactions to that vendor across all award types, a figure that includes research grants and cannot be decomposed without a query capability this review did not have.

And the reporting resolution fell as the activity grew. Interior's fiscal 2023 report names aerial ignition among top mission categories for four bureaus and gives no flight count or hour figure. Interior's fiscal 2024 report, covering 7,833 drone flights and a 27 percent increase, contains no dedicated unmanned aircraft aerial ignition statistics at all; aerial ignition appears only under crewed aircraft.

What is not published anywhere, in any year: acres ignited by helicopter plastic sphere dispenser or helitorch; spheres dispensed by helicopter; the wildfire versus prescribed fire split of aerial ignition acres. The Forest Service fiscal year reports do split aerial ignition hours between wildland fire and prescribed fire, and in both years where the split was published the wildland fire share exceeded the prescribed fire share. The acreage figures are reported as "treated," which is prescribed fire framing, and the split is not given.

What is counted, and what that proves

There is an important correction to make to any claim that ignition consumables are uncounted. **They are counted, for drones, by the Forest Service.** Sphere counts and acres ignited are published in the unmanned aircraft annual reports. That demonstrates the agency can count ignition acres, has a method, and publishes it when it chooses to. It does not do so for helicopter delivery, and it does not do so for the wildfire side of the ledger.

The contrast with retardant is the cleanest way to see the choice. The National Interagency Coordination Center publishes retardant gallons every year, and one delivery system alone accounted for 871,205 gallons in 2024. Aerial ignition consumables delivered by helicopter are not counted at all.

The safety case

The case for replacing crewed aerial ignition with drones is real, traceable to named fatalities, and endorsed by the investigation of one of those fatalities.

The mechanism is specific. Plastic sphere dispenser accuracy requires flight at roughly 120 feet above ground level, and the Facilitated Learning Analysis of the March 27, 2019, Sam Houston National Forest crash found that this "limits pilot reaction time, particularly over dense canopy." That crash killed a Forest Service Plastic Sphere Dispenser Operator with 23 years of service. The analysis recommended exploring "alternatives to helicopter-dependent operations, including expanded UTV use for baseline establishment and Unmanned Aerial Systems (UAS) development."

A Forest Service program lead quantifies the substitution: "Over the last eight or nine years, we've had multiple helicopter crashes that resulted in fatalities. They were all within that low and slow mission profile. We've seen a big shift though, because for about 80% of the burns that we're doing with UAS, the original intent was to perform those tasks with a helicopter."

On ground crews: drone ignition spares firefighters "miles of steep terrain saddled with heavy gear and exposure to rolling rocks, falling trees or risky helicopter flights." On smoke and darkness: "With the use of infrared sensors, drones can fly through highly smoky situations or night flights providing reconnaissance and other aerial needed operations where helicopters could not." On cost: a peer-reviewed operational study reports helicopter operation at 14,200 dollars more per day than the drone alternative, with sphere cost at 2.66 dollars per hectare.

Interior reports zero small, unmanned aircraft mishaps in fiscal 2023 and fiscal 2024 and a five-year rate of 3.63 per 100,000 flights, consistent with the substitution working. No mishap rate is broken out by mission type, so there is no ignition-specific figure.

Nothing in this review undercuts the aviation safety rationale. What the review establishes is that the fire produced by the new method has not been characterized, and that a safety argument about the delivery platform has been allowed to substitute for an effects argument about the fire.

What has been studied

Two peer-reviewed studies address the fire effects of drone ignition. That is the complete set.

The first is a retrospective operational comparison within one private lands prescribed fire program in Texas and Louisiana: 58 drone burns, 62 concurrent non-drone burns, 6,273 hectares, 49,964 spheres at 7.8 per hectare. Drone burns were 129 percent more efficient, 108 hectares per day against 47. Post-burn metrics on a subset showed significantly less severe outcomes for substrate burn severity, vegetation burn severity and char height, and no significant difference for percent unburned area. It measured no fire behavior variable, no emissions, no fuel consumption, no vegetation or soil response beyond ocular severity, and it had no randomization, no paired units, and no control for weather or fuel differences between drone and non-drone burn days.

The second is a single 441-hectare burn on a national forest in Alabama, ignited with 2,712 spheres over 18 flights totaling 196 minutes in a grid pattern on ridgetops, with flanking and backing fire spreading into drains. Thermocouple probes yielded a near-ground heat index, time to maximum temperature, and integrated area under the temperature curve, which is real near-surface fire behavior. Effects were "similar to those from ground-ignited prescribed fires on the same stand in previous years." It is one burn, with no replication and no contemporaneous control, compared against prior years and therefore confounded with weather, fuel accumulation and season.

Both are prescribed fire studies. Neither is a wildfire study. Beyond them:

- No study compares aerially ignited fire to naturally spreading wildfire in ecological or fire behavior outcomes.
- No study compares helicopter plastic sphere dispenser or helitorch ignition to hand ignition in fire effects. The helicopter-delivered majority of aerial ignition history, spanning four decades, is unstudied for effects.
- No emissions work distinguishes aerially ignited area.

The ignition pattern paradox

The most policy-relevant ignition pattern study in American fire science models the geometry that aerial ignition produces without mentioning aerial ignition.

A 2024 study ran 42 physics-based simulations across 14 longleaf pine forest structures, comparing strip-head ignition, dot ignition at two-meter points spaced ten meters apart, and alternating dot ignition. Strip-head ignition produced significantly greater crown scorch and greater total crown damage than dot ignition, attributed to "enhanced convective cooling in fragmented fire lines versus concentrated energy from strip-head patterns." The authors name their own gaps: "ignition line length, variable dash and gap lengths, ignition timings and intensities, pace of ignition, line orientation relative to topography."

Dot ignition at fixed spacing is exactly what a sphere dispenser produces. The study is ground-ignition geometry only.

A field study in Mediterranean pine forests closes the loop from pattern to the variable that matters most for ground effects. Across 77 sampling units on 23 prescribed fires, ignition pattern alone changed fire behavior substantially: strip-heading fire increased spread rate more than 3.5-fold and flame length more than 1.95-fold by changing only the spacing between ignition lines; flanking fire roughly halved spread rate; and spot-heading fire reduced spread rate by more than 78 percent and flame length by more than 41 percent while **increasing flame residence time by 39 to 132 percent** at the widest point spacings.

Residence time is what determines duff consumption, soil heating depth, and old tree mortality. Ignition geometry is what a firing boss and a sphere dispenser set. That link is measured, published, and absent from every operational decision support system in use.

Behind it sits the physics review that has been waiting fifteen years for operational uptake:

> *"The character of a wildland fire can change dramatically in the presence of another nearby fire.* ***Interactions can be created intentionally during prescribed fires by using spatial ignition patterns.*** *Mass fires are among the most extreme examples of interactive behavior. This paper presents a review of the detailed effects of fire-fire interaction in terms of merging or coalescence criteria, burning rates, flame dimensions, flame temperature, indraft velocity, pulsation, and convection column dynamics.* ***Though relevant in many situations, these changes in fire behavior have yet to be included in any operational-fire models or decision support systems.****"*

That was 2011. The delivery technology has since quadrupled its rate. The coalescence physics that multi-point ignition creates remains absent from the models used to plan the operations that create it.

The safety and accountability record for aerial ignition

Three documents matter, and a fourth absence.

The Quarry Fire Aerial Ignition Devices Rapid Lesson Sharing, October 5, 2023, Stanislaus National Forest. Spheres manufactured July 14 to 17, 2023, instead of igniting at 20 to 30 seconds, "would start smoking at around 5-10 seconds, and the fire ignition would occur at approximately 15 seconds." Injected with slightly more glycol, "the average reaction would be for one egg to rocket into the air 25 feet or higher," and when they burst, "The sound was similar to a small caliber bullet." Cause: "an additive that the manufacturer puts into the eggs with the potassium to slow the reaction time, was inadvertently omitted causing the contents of the eggs to look and react differently." The additive is not named. The finding reached interagency circulation as a tech bulletin dated

October 26, 2023, which confirms the manufacturing window, records that the defect resides in the spheres and affects three separate deployment mechanisms including a drone system, a handheld device and a hand launcher, and notes that "A similar issue was discovered in 2013, when reaction was observed with SEI Industries (SEI) Premo plastic spheres and this issue was later resolved." One consumable, two premature-ignition defects in a decade, feeding helicopter machines, drone machines and hand launchers alike.

The Brittle Escaped Prescribed Fire, April 23, 2021, Huron-Manistee National Forest. This is the most instructive aerial ignition escape in the public record because the review is thorough and the sequence is minute by minute. A Bell 407 with a plastic sphere dispenser was requested at 11:17 a.m., overhead at 11:41, and began ignition at 11:51. After four passes the operation paused to let lines merge. At about 12:08 the aircrew observed a northerly wind at roughly 750 feet above ground level. The pattern changed, and the helicopter "then made 10 total passes." Then the operation failed for a reason no equipment log would capture: "Smoke from the initial lines of aerial ignition laid over the burn unit, decreasing visibility for the helicopter," the crew could not tie the lines in, and a head fire developed where a flanking fire was intended. The first spot fire crossed a road at 12:15. Firing stopped at 12:52. At 12:53 the burn boss observed "fire with flame lengths of 20' cross the road." Relative humidity fell to 18 percent against a 30 percent prescription. The fire was declared a wildfire at 2:24 p.m. and reached roughly 5,781 acres. No equipment malfunction is reported. The analysis faults reliance on a single ignition platform without contingency, a burn plan written in 2019 that no longer matched conditions, and a prescription implemented at the hot end of several parameters at once.

The September 2022 National Prescribed Fire Program Review. The agency's flagship self-examination after the 2022 escapes contains no mention of aerial ignition, helitorch, or plastic sphere dispensers. Its only drone references are that "Tools such as drones and infrared devices are not fully used in monitoring and patrolling prescribed fires," and a recommendation to "Increase the use of new technology, including infrared for prescribed fire monitoring, unmanned aircraft systems for ignitions and monitoring." The same review finds that "monitoring and documentation of the effects of fuels treatments and burn day activities are often incomplete." **The agency recommended scaling a technique its own review never examined.**

And the current suppression directives are silent on it. The Interior direction of April 8, 2026 states "the presumption of a full suppression strategy applied to every wildfire under DOI management" and that "While indirect approaches may occasionally be warranted, direct suppression should remain the default," and it gates prescribed fire above Preparedness Level 3 behind Geographic Area Fire Chief approval. The Agriculture memorandum of April 29, 2026 and the Chief's Letters of Intent for 2025 and 2026 say nothing about burnout, firing operations, or aerial ignition; the 2026 letter retains "indirect tactics when necessary."

The significance runs both ways. These directives explicitly gate **prescribed** fire while saying nothing about ignition conducted under a suppression strategy. A full-suppression posture that permits indirect attack when necessary tends to increase burnout, and therefore aerial ignition, which is the one form of deliberate large-scale burning that the directives neither gate nor require anyone to document.

Part 3. What the national archive actually contains

The figures in this part were computed for this review by direct query against the National Incident Feature Service annual archives published through the National Interagency Fire Center's geospatial organization. The

queries are reproducible by anyone in an afternoon, and the exact method is given at the end of this part so that they can be checked.

Burnout is a recorded feature, and it is recorded thinly

Under NWCG Standards for Geospatial Operations, Completed Burnout is one of seven completed fireline feature categories, alongside Completed Dozer Line, Completed Hand Line, Completed Fuel Break, Completed Plow Line, Completed Mixed Construction Line, and Completed Road as Line. Companion categories Planned Burnout and Active Burnout also exist. These features are collected on large incidents and archived annually.

The archive rows are edit-history snapshots rather than physical features. In the 2024 archive there are 2,061 Completed Burnout rows against 419 distinct source features, roughly 4.9 archived versions per feature. Any figure computed from raw row counts therefore overstates by about fivefold and must be deduplicated. The table below uses distinct source features for counts. For length, both the burnout figure and the all-fireline figure carry the same version inflation, so the **ratio** between them is the defensible quantity and the absolute mileages are upper bounds.

Year	Burnout features	All completed fireline features	Burnout share of features	Burnout recorded length, miles	All completed fireline, miles	Burnout share of length
2022	207	17,296	1.20 percent	1,031	65,556	1.57 percent
2023	190	13,413	1.42 percent	489	38,935	1.26 percent
2024	419	42,999	0.97 percent	3,291	149,743	2.20 percent
2025	312	32,698	0.95 percent	2,187	123,527	1.77 percent
Total	1,128	106,406	1.06 percent	6,999	377,760	1.85 percent

The incident-level finding is the important one

Year	Incidents with any mapped completed fireline	Incidents with any mapped burnout	Share
2024	988	105	10.6 percent
2025	1,865	109	5.8 percent

Roughly one incident in ten, falling to one in seventeen.

Now set that against the doctrine quoted in Part 1. Indirect attack, by NWCG's own definition, means the intervening fuel "is usually backfired." The agency tactics guide states that a line not burned out "is almost worthless." Fireline effectiveness research across 33 large western fires found that dozer line accounted for 3,441 kilometers, road as completed line 2,056 kilometers, and hand line 632 kilometers, and did not report burnout as a category at all.

Two readings are possible. Either burnout is a rare tactic used on one incident in ten and accounting for under two percent of completed fireline, which contradicts doctrine and every practitioner account. Or burnout is routinely done and routinely not mapped.

Everything else in this review points to the second reading. No written firing plan is required on a wildfire. No standard requires a record of acres ignited. Line width is populated on under one percent of burnout features. The geospatial standard states that required elements "must be fully populated during the incident," and the quality-assured national extract of this archive found that 17 percent of all fireline features lacked linking identification, that more than 600,000 duplicate features required removal, that line width "remains unreported approximately 80 percent of the time," and that "not all fireline constructed during wildfire suppression efforts have been mapped."

The finding to carry forward is this: the only national geospatial record of firefighter ignition is thin enough that using it as a measure of the practice would understate the practice, and nobody knows by how much.

Burnout has no area

Completed Burnout does not exist as a polygon. Queried for any category matching burnout, the 2024 Event Polygon layer returns zero. Its distinct category values are two: Wildfire Daily Fire Perimeter and Prescribed Fire. Its own feature type and renderer definitions enumerate three, adding only Other. The layer is not empty; it holds roughly 100,000 features in 2023. It contains no burnout geometry with area.

The fallback route to area is closed as well. The line schema carries a Line/Width/Feet attribute. For Completed Burnout features it is populated on 11 of 2,061 archived rows in 2024 and 17 of 733 in 2023. Under one percent, and just over two percent. Without width, miles of fired line cannot be converted into acres by any defensible method.

One limitation should travel with this finding. The annual archive descriptions state that the published exports have "sensitive fields and features removed," so it is conceivable that burnout polygons exist in the live authenticated service and are filtered from the public archive. Two things argue against that reading: burnout is not plausibly sensitive when evacuation and closure areas were retained in the 2018 archive, and a row-level filter would not remove the category from the layer's renderer definition. Closing the question requires a query against the live service, which is a reasonable records request.

Method, for replication

The services are published under the National Interagency Fire Center's ArcGIS organization as annual Operational Data Archive feature services. Layer identifiers are not stable across years and must be read from each service root. Counts of distinct physical features use a distinct-value query on the source global identifier field. Category filters match on the FeatureCategory field. Length sums use the hand-entered LengthFeet attribute; the geometry length field is in Web Mercator units and would require reprojection before use. Incident counts use distinct values of the incident name field, which is inflated by naming variants and deflated by nulls, so it brackets rather than fixes the true count.

Two computations could not be completed here and should be done by anyone with unrestricted network access. First, deduplicated length: summing the maximum recorded length per distinct feature rather than across all versions. Second, and more valuable, the published quality-assured fireline dataset for 2017 through 2024 retains Completed Burnout as one of its seven construction types and carries an engagement outcome field with values of held, burned over, and not engaged. **Nobody has published the burnout rows of that dataset.** Computing burnout mileage from geometry, and burnout engagement outcome rates against the other six construction types, is a single summarize operation on a federal dataset that has already been released, quality assured, and documented. It would be the first honest measure of firing operation effectiveness the United States has ever

published. The host serving that dataset was blocked by network policy for this review; it is not blocked for the agencies that published it.

Part 4. Why intentional ignition at scale must be a variable in fire research

The case for treating suppression firing as a covariate does not depend on any claim about whether it is good or bad. It rests on four propositions, three established and one open.

Proposition 1: the acreage is large enough to matter, and nobody knows how large

Established. The only systematic quantification anywhere examined 74 fires of 500 hectares or larger in Victoria, Australia, from 2010 to 2015. Suppression firing occurred on 34 and was mappable on 26. On the mapped fires the proportion of final area attributable to suppression firing had a mean of 0.29, a median of 0.24, a minimum of 0.07 and a maximum of 0.94, with absolute area from under 1 hectare to about 20,000 hectares, exceeding 500 hectares on half the mapped fires, including a single operation of about 9,000 hectares inside a 36,000 hectare fire. Firing ran along 42 percent of the external perimeter of the mapped subset and 19 percent of the total external perimeter across all 74 fires.

The same paper states of the United States: "In the USA, the cumulative size and severity of suppression firing operations is currently unknown." It adds two cautions that any American replication will face. On detection: "Unidentified suppression firing may confound the remote assessment of fires as multiple sources of operational data were often needed for clear demarcation." On inference from absence: "Absence cannot be taken as evidence that the practice did not occur, only that it was not recorded."

And on the ecological question, it is explicit that it did not answer it: "The testing of these theories and other fire ecology effects is an identifiable research gap, and conclusions on such matters were beyond the scope of this research." That is a published, peer-reviewed statement of the gap by authors who held the operational data.

Proposition 2: free-spreading fire skips ground, and deliberate ignition is designed not to

Established on both halves.

Fire refugia within perimeters are well quantified and method-dependent. Across studies, unburned proportion inside perimeters runs from 9.6 percent to 37 percent depending on region and method, with topography explaining between 4 and 50 percent of the variation depending on terrain and fire weather. Unburned proportion decreases with increasing fire size and severity, and refugia shrink and become less predictable under extreme weather.

The intent on the other side is explicit. The verb in both NWCG definitions is “consume.” The firing curriculum describes managing heat production and flame lengths through firing pattern and timing. The tactics guide states that burnouts "are very successful at night as long as RH stays low."

One caution belongs here for anyone building an argument on refugia. The fires on which firing operations are most used are exactly the large, extreme-weather fires where unburned fraction is already lowest, so the margin available for firing to eliminate is smaller than the headline percentages suggest.

Proposition 3: ignition pattern changes fire behavior, and the operational models do not know it

Established, and stated by the authors of the governing review and confirmed in the field.

The 2011 review establishes that fire-fire interaction alters "merging or coalescence criteria, burning rates, flame dimensions, flame temperature, indraft velocity, pulsation, and convection column dynamics," that such interactions "can be created intentionally during prescribed fires by using spatial ignition patterns," that in discontinuous fuels they "may elicit fire spread where none otherwise existed," and that these effects "have yet to be included in any operational-fire models or decision support systems."

The field evidence is now specific. Changing only the spacing between ignition lines increased spread rate more than 3.5-fold and flame length more than 1.95-fold; spot-heading ignition at wide spacing increased flame residence time by 39 to 132 percent. Paired backing and heading fires showed backing fire holding temperature above the lethal 60-degree Celsius threshold an average of 54 seconds longer.

That last number is the hinge of everything in Part 5. Residence time is what kills old trees through duff smoldering, what drives soil heating depth, and what governs the smoldering emissions that standard emission factors predict poorly. Residence time is set by ignition geometry. Ignition geometry is a firing boss decision and a sphere dispenser setting.

Report the null alongside it. A paired experiment in loblolly pine found that firing technique changed residence time as described but did **not** change midstory vegetation response one growing season later, while fire season did, with May and June mortality three to four times that of other seasons. The physical difference is real and measured. Whether it propagates to a given ecological endpoint is an open question that depends on the endpoint.

Proposition 4: the completeness hypothesis, stated as a hypothesis

The claim. Systematically ignited fire burns the ground more completely than fire that spreads on its own, because free-spreading fire leaves islands, skips terrain, and lays down at night, while deliberate ignition is applied across a unit until the fuel carries. If true, intentional ignition inflates both total burned acres and the completeness of consumption within a perimeter relative to what the same fire would have done unaided.

Status: untested. There is no field measurement anywhere in the literature of pre- and post-fire fuel loading inside a mapped burnout paired with a free-burn control on the same fire, in any fuel type.

The indirect evidence runs in both directions, and both directions should be stated.

Against the strong form: generally, two to four times more fuel is consumed in a wildfire than in a prescribed fire, because wildfire fuels are drier and crowns ignite, while deliberate ignition is scheduled when large fuel and forest floor moistures are high. Suppression firing in the one jurisdiction where it was observed "occurred during intervals of low fire spread and resulted in modest fire behaviour," which is the prescribed fire window. And deliberate ignition does not in fact produce complete consumption: measured hand-ignited burns in heavy Sierra Nevada fuels burned between 24 and 96 percent of the ground surface in early season plots and 47 to 100 percent late season, governed by fuel continuity, bare ground, slope and moisture rather than by ignition.

For the hypothesis: coalescence physics is real, deliberately exploited, and can carry fire through fuel that would not otherwise have carried it. The doctrinal intent is consumption. And the residence time findings in Proposition 3 predict exactly the divergence that would let a tactic register as low severity on a canopy index while consuming more of the forest floor.

The one direct test, and what it did and did not measure. A 2024 study mapped firing operations as polygons across 133,000 hectares of the northern arm of the 2021 Dixie Fire, using the national incident archive, decision support records, park service documents and incident action plans, refined by consensus with assigned fire personnel who reviewed the fire day by day. The response variable was a Landsat-derived composite burn index across 6,358 samples; the model explained 56 percent of variance. The study area was 48 percent high severity and 26 percent each low and moderate.

Offensive firing inside prior low-severity fire footprints reduced composite burn index by 40 to 49 percent. Prior moderate-severity fire alone reduced it by 19 percent. Within prior high-severity patches, operations dampened severity across all categories. Defensive firing outside prior fire footprints increased severity by 1 percent and medium operations by 4 percent. The authors address the narrative head-on: "One often repeated narrative on firing operations is that defensive firing operations, in particular, tend to produce undesirable high-severity fire effects. However, the modest effect of defensive firing we identified suggests that its potential to increase fire severity may be overstated since this tactic is used at times and locations when extreme fire weather, heavy fuels and rugged terrain already make high-severity fire effects more likely."

What they did not test matters as much. Composite burn index is canopy-weighted and is not a measure of forest floor, duff, or coarse woody consumption, which is what the completeness hypothesis is about. They ran no refugia or patch-structure analysis, so a tactic that converts zero-index refugia into low-severity burn while lowering the mean would be invisible. They state that the analysis "was spatially implicit, so it did not account for the effects of operations and fuel treatments on fire behavior and ultimately fire severity patterns beyond their immediate footprints," and that the paper "focuses on severity, not area burned." And offensive firing was deployable precisely because prior low-severity fire made it safe, so the modeled counterfactual cannot fully separate "firing lowered severity" from "firing was attempted where severity would have been low."

Their own methodological conclusion is the one that indicts the record: "Estimating the effects of operations using archival incident data alone is likely insufficient for reconstructing operations during large, complex megafires," because "complete spatial characterization of suppression operations (especially for past fires) requires integration of available data with firsthand observations from fire line personnel."

The correct statement. The completeness hypothesis is coherent, consequential, and unmeasured. The one study bearing on it used a metric systematically insensitive to the mechanism claimed and found the opposite sign on the metric it did measure. Anyone asserting the strong form is asserting past the evidence. Anyone dismissing it is dismissing a question nobody has asked.

Naming it is the useful step. A hypothesis with a name, a mechanism, and a specified experiment can be funded and tested. An assertion cannot.

Part 5. Consequences: six questions that cannot currently be answered

This part does not argue that suppression firing harms these resources. It argues something narrower and harder to dismiss. For each resource, fire effects are known to depend on variables that firing operations directly control: timing, season, time of day, intensity, residence time, spatial pattern, and completeness of consumption. And for each resource, searches of the research literature conducted for this review returned no study in which ignition source appears as a predictor, a stratum, or a covariate.

Those negatives are absence-of-hits results across three literature indexes. They are not proof of nonexistence and are stated here as what they are.

Smoke and public exposure

Emission factors partition by combustion mode. Carbon dioxide, nitrogen oxides, sulfur dioxide and black carbon track flaming; carbon monoxide, methane, ammonia, most non-methane organic compounds and organic aerosol track smoldering. Modified combustion efficiency runs near 0.99 for pure flaming against 0.65 to 0.85 for smoldering. And the standard framework predicts poorly for exactly the fuels that matter here: laboratory measurements of pure smoldering combustion of duff, organic soils and large woody fuels show poor correlation between combustion efficiency and emission factors.

Fuel moisture is the switch. In controlled burns of identical fuel beds at prescribed-fire versus drought-wildfire moisture, duff did not ignite at the wetter condition; at the drier condition duff ignited, smoldering was prolonged, and organic carbon emissions and secondary organic carbon formation were an order of magnitude higher.

So a burnout fired at night under humidity recovery and a burnout fired at midday in drought-dry duff are not the same emissions event, and neither is the same as free-spreading head fire. None of the three is distinguished in any emissions inventory. Inventories compute emissions from burned area, modeled fuel loads and combustion completeness, differentiate fire type by land cover, and make no distinction between natural and human ignition or between wildfire, prescribed fire and suppression firing.

One caution against overstating: recent work finds that prescribed fire is unlikely to reduce net fine particulate emissions in most locations, and that prescribed fire smoke would need to be nine to sixteen times less harmful per kilogram than wildfire smoke to break even. The argument here does not need the claim that planned fire smoke is cleaner. It needs only that emissions depend on combustion regime, which is established.

The question that cannot be answered: what fraction of the fine particulate burden attributed to any given large wildfire was produced by fuel deliberately ignited by firefighters, and under what combustion regime.

Old growth and large trees

This is the domain where the mechanism in Part 4 has the most direct consequence, and where the evidence base is strongest.

Fire-caused tree mortality is not reducible to crown scorch. Long-term smoldering combustion conducts heat through soil to lethal temperatures that kill roots. Mineral soil is a poor conductor and the organic layer insulates roots from flames, which means the duff is both the insulation and, once it ignites, the delivery mechanism. The authoritative synthesis notes that surface fuel consumption near tree bases is under-represented in mortality models despite mattering most "for shallow-rooted species, seedlings, and in long-unburned areas," and that "Tissue lethal exposure time is unresolved for the elevated temperatures that occur in fires." Duration, not peak temperature, is the unresolved variable. Duration is what firing pattern sets.

The controlling variable has been isolated experimentally. In long-unburned longleaf pine stands burned at wet, moist and dry duff moisture, duff reduction was greatest in dry burns at a mean of 46.5 percent, and overstory mortality was greatest in dry burns, while pine mortality in the wet and moist treatments did not differ from unburned controls. The best predictors of individual pine mortality were duff consumption and crown scorch. Long-unburned stands accumulate duff eight to twelve inches deep, smoldering can persist for days to weeks,

and mortality is typically delayed twelve to eighteen months and is highest in the larger tree classes. The Forest Service published a dedicated synthesis on mitigating old tree mortality in long-unburned forests, which is itself evidence that the agency understands this mechanism and manages for it, on prescribed fires.

The stakes are quantified. In the 2020 and 2021 fires, an estimated 7,974 giant sequoias died, 30.2 percent of the trees studied, and prescribed burning within the prior ten years reduced mortality odds by 77 percent. The mechanism was surface fuel reduction: ladder fuels, height heterogeneity and canopy density showed no clear effects.

The question that cannot be answered: of the large and old trees killed inside a given fire perimeter, how many were killed by fire that crews put on the ground during holding operations, and did those trees die by duff smoldering under humidity recovery rather than by the head fire. There is no study in which ignition source is a predictor of tree mortality.

Amphibians and aquatic species

The Sierra Nevada yellow-legged frog was listed as endangered in 2014; four distinct population segments of the foothill yellow-legged frog were listed in 2023 with critical habitat designated in 2025. After the 2021 Dixie Fire, foothill yellow-legged frog probability of occurrence was 4.93 times higher outside the fire footprint than within it, 0.21 against 0.05, with measured environmental characteristics similar inside and out. **That study does not examine fire severity, suppression activity, or ignition source.** It is a clean negative on the fire most likely to have involved extensive burnout.

The mechanism that connects firing pattern to amphibian outcome is spatial. Breeding persistence is negatively related to the percentage of the 100 meter terrestrial buffer around breeding ponds that burned, and colonization of unoccupied ponds is low regardless of severity. Burnout deliberately removes unburned interior area.

The asymmetry in this domain is stark and fully documented. Retardant dropped to hold the line carries a mandatory buffer: "Waterways will be avoided and are given a minimum of a 300-foot buffer, including perennial streams, intermittent streams, lakes, ponds, identified springs, reservoirs, and vernal pools," with avoidance areas also covering listed species habitat. And it carries a reporting duty: "The Forest Service will report to FWS and NOAA fisheries (as appropriate) all misapplications of aerially applied fire retardant. The report and assessment of impacts will determine necessary mitigation measures, remediation action, monitoring needs, and whether there is a need for reinitiation of formal consultation." Toxicity is measurable: a 96-hour median lethal concentration for Atlantic salmon parr at pH 6.4 of 0.030 to 0.146 milligrams of ammonia nitrogen per litre, with a level of concern for sensitive listed species set at 0.05.

The question that cannot be answered: whether reduced occupancy inside a fire footprint occurred disproportionately in areas burned by suppression firing rather than by free-spreading fire. And the asymmetry to note: the chemical delivered to hold the line carries a 300-foot buffer and a misapplication reporting duty, while the fire lit off that line carries neither.

Riparian areas and streams

Riparian zones function as relative fire refugia, burning less frequently and at lower severity than adjacent uplands in much of the western United States. State this as relative rather than absolute, because the literature is genuinely mixed: riparian and adjacent upland forests have been shown to burn synchronously in dry years, and

at least one study set out specifically to test and complicate the assumption that areas adjacent to streams do not burn.

The relevant mechanism is that a burnout fired from a ridge road downhill to a stream converts a refugium into burned ground. The relevant asymmetry is that planned riparian burning is small, cautious, and coordinated: a survey of 74 Forest Service fire management officers found 43 percent conducting riparian fuel treatments, 93 percent of projects under 300 acres, designed "in ways to minimize negative impacts on species and habitats," with the authors concluding that well-designed monitoring "is needed to provide a scientifically defensible basis." Post-fire, the standing recommendation is that "providing postfire riparian zones with the same environmental protections they received before they burned is justified ecologically."

The question that cannot be answered: how much riparian area inside large fire perimeters was burned by fire lit from ridge roads and fired downhill, and whether refugial function was lost in those reaches. No riparian buffer binding on suppression firing, comparable to the riparian reserve standards governing planned management activities, was located.

Type conversion and reburn

Conversion risk projections run from 1.6 to 15.1 percent of intermountain forest by mid-century, up to 30 percent in the Southwest under extreme fire weather. Short-interval fires undermine resilience by removing seed sources before maturity, and the spatial pattern of what survives is a conversion-relevant variable. Reburn severity is predictable: initial severity interacting with time since fire explained 43 percent of reburn severity variance in a northern Sierra Nevada study, with thresholds of snag basal area above 43 square metres per hectare and shrub cover above 60 percent predicting high severity reburn above 27.3 degrees Celsius.

In southern California chaparral, of plots initially above 75 percent woody cover, 59 percent declined and 28 percent of those converted heavily to herbaceous dominance, with **minimum fire interval shorter than 15 years the top distinguishing variable.**

That threshold makes the question quantitatively consequential. If roughly a quarter of large-fire area is firefighter-ignited, then a burnout that adds a burn entry inside a 15-year window is, on this evidence, a type conversion risk event.

The question that cannot be answered: what fraction of short interval reburns, and therefore of conversion risk, is attributable to intentional ignition rather than to fire arrival.

Soils, water, and post-fire hazard

The federal text says it plainly. From the Forest Service synthesis on fire effects to soil and water: "Because the rate at which energy can be transmitted through the soil is limited by the soil's thermal properties, the duration of burning is critically important to the effects on soils." And: "fire intensity is not necessarily a good measure of the amount of energy transmitted downward into the soil." And: "The range of fire effects on soil resources can be expected to vary directly with the depth of burn as reflected in the amount of duff consumed and degree of large woody fuel consumption." And: "the depth of lethal heat penetration into the soil can be expected to increase with the increasing depth of surface duff that is burned."

Soil burn severity is the operative mapping variable for Burned Area Emergency Response, which drives post-fire debris flow assessment, emergency treatment prescriptions, and cost. No burned area emergency response product located for this review attributes any mapped soil burn severity to ignition source.

The question that cannot be answered: what fraction of the high soil burn severity area driving a post-fire debris flow assessment was produced by suppression firing. This matters in dollars as well as in ecology, because emergency treatment cost and downstream hazard are conditioned on exactly this variable.

Part 6. Four regulatory asymmetries

The same fuel, lit by the same person, with the same torch, on the same ground, is governed by four different regimes depending on whether a burn plan exists. These are not gaps in science. They are gaps in law and policy, and they are the reason the science gap has persisted.

One. Air quality

Under the federal Exceptional Events Rule, wildfire is defined to include "any fire started by an unplanned ignition caused by lightning; volcanoes; other acts of nature; unauthorized activity; or accidental human-caused actions, or a prescribed fire that has developed into a wildfire," and as a natural event it satisfies the rule's "unlikely to recur" criterion without further demonstration. A prescribed fire must be shown not reasonably controllable or preventable, either by demonstrating it was conducted under an adopted and implemented certified smoke management plan, or that the burn manager employed appropriate basic smoke management practices with documented interagency collaboration, and must additionally show it was not reasonably preventable by describing the benefits that would have been foregone.

Fuel ignited by a firefighter inside a wildfire is wildfire smoke for these purposes and carries none of that burden. The same fuel, the same firefighter, the same torch, under a burn plan, carries all of it. The current NWCG smoke management guidance is scoped by its title to prescribed fire.

Two. Resource protection

The prescribed fire planning guide requires, before ignition, documented compliance with the National Environmental Policy Act, the National Historic Preservation Act and the Endangered Species Act. Its fourth required element directs the planner to "List and discuss special features, natural resources, values, hazards, issues and constraints including those identified in NEPA. Examples may include: Wildland Urban Interface (WUI) areas, fences to protect power poles, historical sites, cultural sites, threatened and endangered species or habitat, etc."

On an incident, Endangered Species Act compliance runs through the emergency provision, which allows consultation to be "conducted informally through alternative procedures," with formal consultation initiated "as soon as practicable after the emergency is under control." Resource protection is delivered through a Resource Advisor, whose assignment is at the agency administrator's discretion, whose role is to provide "daily input to the Incident Commander," and whose "operational direction comes from the IC or IMT."

Advice is not a constraint. A Resource Advisor can recommend that a division not be fired downhill into occupied habitat. A burn plan element is a condition of ignition.

Three. Monitoring

The prescribed fire guide requires, in its monitoring element: "Monitor, obtain and record weather data. Monitor and record fire behavior data throughout the burn operations. Monitor and record smoke management information. Monitor and record first-order fire effects."

Nothing equivalent applies to suppression firing. Burned Area Emergency Response is scoped to identify and manage "imminent post-fire threats," is time-bounded, and handles suppression-caused damage under a separate authority and funding stream for suppression activity damage repair. No post-fire requirement exists to assess or report the effects of a firing operation.

Four. Accountability for the escape

An escaped prescribed fire is counted because it converts to a wildfire, generating a new incident record, a new fire report, and a mandatory escape review. Forty-three escapes out of roughly 50,000 projects were counted that way over a decade, and the Government Accountability Office used that count to evaluate the program.

A burnout that escapes is already inside a wildfire. There is no status to convert to, no new incident number, no reporting trigger, and no mandatory review. NWCG has no glossary term for a firing operation escape. The nearest adjacent term, slop over, does not distinguish whether the crossing fire was the main fire or a firefighter's ignition.

This is structural, not an oversight of data collection. No amount of better compilation will produce a count of escaped burnouts, because nothing in the system generates the record.

The retardant precedent shows the agencies can impose such a duty when they choose to. Every misapplication of aerially delivered retardant is reported to the wildlife agencies, with an assessment of impacts that determines mitigation, remediation, monitoring needs, and whether formal consultation must be reinitiated. That is a fully specified suppression-effects reporting regime, already operating, already funded, already accepted by the field. It exists for the chemical and not for the fire.

Part 7. What is known

Quantity	Best available evidence
Suppression firing as a share of final fire area	Mean 0.29, median 0.24, range 0.07 to 0.94, on 26 mapped fires in Victoria, Australia, 2010 to 2015
Share of external perimeter fired	42 percent of the mapped subset, 19 percent across all 74 fires, Victoria
Completed Burnout features, United States national archive	1,128 distinct features, 2022 through 2025
Burnout share of completed fireline	1.85 percent of recorded length, 1.06 percent of features, 2022 through 2025
Incidents carrying any mapped burnout	105 of 988 in 2024; 109 of 1,865 in 2025
Archive version inflation	4.9 archived rows per distinct feature, 2024 burnout
Line width populated on burnout features	11 of 2,061 rows in 2024; 17 of 733 in 2023

Quantity	Best available evidence
Fireline engagement, all types	Engagement ratio 0 to 0.78, mean 0.40 to 0.59; held to total mean 0.33; roughly half of constructed line never meets fire
Forest Service drone ignition acres	128,913 in fiscal 2023; 188,986 in fiscal 2024
Spheres dropped by Forest Service drones	322,246 in fiscal 2023; 733,115 in fiscal 2024
Forest Service aerial ignition hours	Nearly 140 in fiscal 2022; more than 251 in fiscal 2023; approximately 855 in fiscal 2024
Interagency drone aerial ignition flights	602 in fiscal 2022, 12 percent of all interagency drone flights
Helitorch gelled gasoline delivered	2,846 gallons in calendar 2021; 6,070 gallons in calendar 2022
Drone ignition density in practice	1 sphere per 4 acres to 7.8 spheres per hectare, roughly a thirtyfold range
Dispensing capability	30 spheres per minute in 2019 to 120 by 2022; 45 to 130 per minute for the helicopter Premo Mark III
Federal procurement	10-million-dollar Interior blanket purchase agreement with the dominant drone vendor, 2023 to 2028
Aerial ignition aviation fatalities	Two helicopters and five people lost since 2005, per Interior's own figure
Drone mishaps	Zero small, unmanned aircraft mishaps in fiscal 2023 and 2024; five-year rate 3.63 per 100,000 flights; not broken out by mission
Firing operation severity effect, one fire	Offensive firing reduced composite burn index 40 to 49 percent inside prior fire footprints; defensive firing increased it 1 percent; medium operations 4 percent
Ignition pattern effect on residence time	Spot-heading ignition increased flame residence time 39 to 132 percent at widest spacing; backing fire held above lethal temperature 54 seconds longer than heading fire
Unburned area within free-spreading perimeters	9.6 to 37 percent depending on region and method
Escaped prescribed fires	43 of roughly 50,000 projects, 2012 to 2021, under 1 percent
Escaped burnouts	No definition, no trigger, no review requirement, no count

---

Part 8. What is not known

Each item is a verified absence rather than an unsearched topic.

Scale and accounting

1. Acres burned by suppression firing inside wildfire perimeters, nationally or on any American fire other than one arm of one fire. No acreage field exists anywhere in the federal record.
2. Acres ignited by helicopter plastic sphere dispenser or helitorch, nationally or by year, in any year.
3. The wildfire versus prescribed fire split of aerial ignition acres.
4. Spheres dispensed by helicopter, and gallons of gelled fuel consumed after calendar 2022.

5. Total federal expenditure on aerial ignition, or the cost of any firing operation. Incident job codes answer which incident, not what kind of work.
6. Miles of fireline built per acre burned as a national time series, and cost per mile by construction type.
7. How much burnout goes unmapped. The archive shows burnout on roughly one incident in ten against doctrine that describes it as routine, and nobody has measured the discrepancy.

Effects

8. Fuel consumption inside a mapped burnout paired with a free-burn control on the same fire. No such measurement exists in any fuel type.
9. Whether firing operations reduce fire refugia, eliminate unburned islands, or reduce within-unit severity variance. Asserted in the literature, never tested.
10. Ecological or fire behavior outcomes of aerially ignited fire compared to naturally spreading fire. Zero studies.
11. Fire effects of helicopter plastic sphere dispenser or helitorch ignition compared to hand ignition. Zero studies across four decades.
12. Effects of drone ignition on a wildfire as opposed to a prescribed fire. Both existing case studies are prescribed fire.
13. Threshold behavior across ignition density. Practice spans roughly a thirtyfold range, coalescence physics predicts regime changes across it, and no study locates the thresholds.
14. Whether dense simultaneous aerial ignition can induce plume dominance or mass fire behavior.
15. Emissions as a function of ignition source or ignition pattern.
16. Whether day firing under peak burning conditions produces different effects than night burnout under humidity recovery.
17. Old tree and large tree mortality attributable to firing operations, by duff smoldering or otherwise.
18. Effects of firing operations on listed amphibians, riparian refugia, soil burn severity, or type conversion risk. Ignition source appears as a variable in no study in any of these domains.
19. Aerial ignition's contribution to escaped prescribed fires and to wildfire growth from firing operations.

Safety and accountability

20. Escaped burnouts, as above.
21. Injuries and fatalities attributable to firing specifically. The best severe injury study folds "direct or indirect fireline construction, burnouts or mop-up" into a single Fireline activity category. The entrapment literature does not code tactic.
22. A drone-ignition-specific mishap rate.
23. Any comparison of injury or fatality rates between indirect, firing-based tactics and direct attack. The safety case for firing is doctrinal, not empirical.

Measurement infrastructure

24. Fireline intensity, flame length, rate of spread, residence time, and soil heating duration measured systematically over large areas.

25. A severity field assessment database linking pre-fire conditions, in-fire behavior, ignition source and post-fire effects on the same ground.

Part 9. Why the gap exists

The gap is architectural. Each system that could capture firing operations fails to for a documented reason.

ICS-209. All 53 blocks of the incident status summary were reviewed. Block 7 is Current Incident Size or Area Involved. There is no block for firing operations, burnout acres, backfire, ignition method, or miles of line fired as against constructed. The only places firing can appear are free-text narrative blocks. In the entire 2023 program user's guide the word burnout appears once, as an example of how to phrase a resource request. Burnout acres are absorbed silently into the Block 7 total.

National statistics. These are compiled from Incident Management Situation Reports, which inherit the Block 7 absence. The statistics page carries no caveat about ignition source within perimeters. Prescribed fire is reported on a separate page.

The ledger asymmetry is the cleanest statement of the problem. A drip torch lit under an approved burn plan produces prescribed fire acres. The same drip torch lit inside a wildfire perimeter produces wildfire acres. Same torch, same crew, same fuel, opposite ledger. No agency has ever published the second number.

The Fire Occurrence Database. Thirteen enumerated causes: arson and incendiarism, debris and open burning, equipment and vehicle use, firearms and explosives use, fireworks, misuse of fire by a minor, natural, power generation and transmission, railroad operations, recreation and ceremony, smoking, other causes, and undetermined. Firefighter ignition is not among them. The architecture forecloses it independently, because the database is organized around a single point of origin: one record, one ignition point, one cause, one final size. A database whose unit of analysis is the origin point cannot represent multiple ignition sources within one fire.

Burn severity products. Severity mapping assigns one fire type per perimeter and analyzes severity only. The wildfire definition explicitly absorbs escaped wildland fire use events and escaped prescribed fire projects, so even the one case where agency ignition is unambiguous is relabelled as wildfire. There is no mechanism to partition a perimeter by who lit which part. The severity classes themselves rest on analyst-chosen thresholds not tied to ecological metrics, such that the same index value can be classified low, moderate or high on three different fires.

The national incident geodatabase. This is where the data almost exists, and the failure is the most fixable. Part 3 documents what it contains and what it does not: burnout as a line without area, width populated on under one percent of features, and a record so thin relative to doctrine that it cannot be used as a measure of the practice.

Records retention. Incident Action Plans, assignment sheets and firing briefings are temporary records destroyed seven years after cutoff, with no national archive. The permanently retained records are the Individual Fire Report and the Incident History File.

Decision documentation. The wildland fire decision support system is the system of record for creating, compiling and publishing a decision, and its course of action is strategic. Nothing in the help documentation requires, prompts for, or provides a field for specific tactics such as burnout, backfire or aerial ignition.

Aerial ignition standards. The governing standard requires an aviation safety plan, a briefing, a go and no-go checklist, and equipment maintenance logs. None of those records pattern, spacing, spheres dispensed, or acres burned.

Oversight. Across 2020 to 2026 there is no Government Accountability Office, Inspector General, or Congressional Research Service product examining managed wildfire, indirect attack strategy, acres burned by agency firing operations, or accountability for firing decisions. The nearest miss is instructive. A 2015 report found that agencies "have not consistently followed agency policy" on fire reviews and "have not used specific criteria for the reviews." Oversight looked squarely at whether the agencies can evaluate their own fire decisions, found the review process inadequate, and never asked what the tactics burned. The 2025 wildfire technology survey does not mention aerial ignition at all.

Incident review. The Lessons Learned Center incident review database does contain an incident type value of Firing Operation, and at least 13 records carry it, spanning a firing operation lawsuit, multiple burn injuries, a drone flyaway during aerial ignition, a helitorch gel burn injury, and the sphere defect described in Part 2. But the site-wide search returns identical keyword-irrelevant results for every query, the records are indexed by outcome rather than by tactic, and the index appears to search record summaries rather than attached documents. A complete enumeration requires the incident type filter in a browser, which is a five-minute task for anyone inside the agencies and was not reachable for this review.

This is a blind spot, not a concealment

The pattern is consistent with a shared measurement gap rather than with suppression of information. The flagship paper on how suppression changes fire severity models suppression purely as the selective removal of low-intensity fire and never as an ignition source. The current federal wildfire technology survey omits aerial ignition. The national prescribed fire program review recommended scaling drone ignition without examining it. NWCG archived the umbrella term for the practice. The best ignition-pattern simulation study models the geometry aerial ignition produces without naming it. A concealment would not produce that distribution. An unexamined assumption would.

What does look like an institutional choice rather than an oversight is the ledger. Agency-lit fire under a burn plan is counted as prescribed fire and reported on its own page. The same fire inside a wildfire perimeter is counted as wildfire and reported nowhere separately. That convention is a decision about what to publish. It has survived seventeen years. No oversight body has questioned it.

You have to touch the land to know the land. In this context that is not a slogan but the methodological finding of the only American team that has tried to reconstruct firing operations from the record. They concluded that archival incident data alone was insufficient and that complete characterization "requires integration of available data with firsthand observations from fire line personnel." The people who know where the fire was lit are the people who lit it, and no national data system asks them.

Part 10. Data gathering the agencies can adopt now

Everything in this part uses systems, forms, positions and authorities that already exist. None of it requires new legislation, new appropriations, or a new data system. Items are ordered by how quickly they could be in place.

This season, with no new authority

1. Add burnout acres to the ICS-209. The incident status summary already collects current incident size in Block 7. Add one numeric field: acres burned by intentional ignition this reporting period. The Situation Unit already computes daily growth. A firing boss or division supervisor already knows roughly what was fired. The field costs one line on a form that is filled out daily on every large incident, and it is the single highest-value addition available, because the national acreage statistics are compiled from this form. Until that field exists, no compilation anywhere can separate the two kinds of acres.

2. Draw the burnout polygon. Every large incident has geospatial staff who already map Completed Burnout as a line. Direct them to also map it as an area, using either a new polygon category in the geospatial standard or the existing line category with a required width. The geospatial standard already asserts that required elements "must be fully populated during the incident." This is a data standard amendment that the Incident Operations Subcommittee and the Geospatial Subcommittee could make in one meeting, and it closes a seventeen-year gap.

3. Enforce line width on burnout features. The field exists. It is populated on under one percent of burnout features. Making it required, with a default of the actual fired depth rather than a line symbol, converts miles into acres immediately and retroactively for any future season.

4. Require a one-page firing record above a threshold. Set a threshold, for example any firing operation above a stated acreage or any aerial ignition operation on a wildfire, above which a single page is completed and retained with the permanent incident record rather than the seven-year administrative file. The page records: objective; ignition method and device; intended pattern and spacing; ignition window with observed temperature, relative humidity and wind; holding resources; contingency line; and estimated area to be burned. This is not a burn plan and should not be mistaken for one. It is proportionate documentation of a consequential act. It also closes the loose end where the unmanned aircraft standard directs pilots to follow "approved aerial firing plans" that the aerial ignition standard never requires anyone to write.

5. Restore and extend aerial ignition reporting. The fiscal 2022 interagency report published aerial ignition as a named mission with a flight count. Fiscal 2023 dropped the count and fiscal 2024 dropped the category. Restore it and extend it three ways: report wildfire and prescribed fire separately, which the Forest Service already does for hours; report acres ignited as well as hours, and date the figure; and report consumables for helicopter delivery as the Forest Service already does for drones. Retardant gallons are published every year. There is no principled reason ignition consumables are not.

6. Publish the burnout rows of the fireline dataset. The quality-assured national fireline dataset for 2017 through 2024 already retains Completed Burnout as one of seven construction types and already carries engagement outcomes of held, burned over, and not engaged. Publishing two figures annually, burnout mileage by year and region, and burnout engagement outcome rates against the other six construction types, costs one summarize operation on a dataset the agencies have already released. It would be the first measure of firing operation effectiveness the United States has ever published.

This year, with existing authority

7. Define and count the firing operation escape. Define it, for example, as a firing operation that crosses its intended holding feature and requires additional line construction or produces unintended fire growth. Require a short, standardized report when one occurs. Publish the annual count and the rate against burnout miles. This is the direct analogue of the prescribed fire escape count, and it is the only way the practice can ever be evaluated the way the prescribed fire program was.

8. Add ignition source to post-fire assessment. Burned area emergency response and vegetation condition products are produced on most large federal fires. Neither record whether an area was fired. Overlaying a burnout layer, once it has area, onto soil burn severity and vegetation mortality products generates a national effects dataset as a byproduct of work already being done, at close to zero marginal cost.

9. Give the Resource Advisor a firing trigger. The Resource Advisor position, the qualification, and the guide all exist. Add one provision: before a firing operation above the threshold in item 4, the Resource Advisor is consulted on identified resource values inside the intended burn area, and the consultation is recorded on the one-page firing record. This is not a veto and does not change the incident commander's authority. It creates the record that currently does not exist, and it uses a position the agencies already deploy.

10. Apply the retardant precedent to fire. Every misapplication of aerially delivered retardant is reported to the wildlife agencies with an assessment of impacts that determines mitigation, remediation, monitoring needs, and whether consultation must be reinitiated. That regime is specified, funded, and accepted by the field. Extend the same reporting duty to firing operations that burn into a designated avoidance area, critical habitat, an inventoried riparian reserve, or a mapped old growth stand. The agencies already know how to do this because they already do it for the chemical.

Next season, with modest investment

11. Map firing to sub-daily resolution on a sample of incidents. Device, time, pattern, spacing, ignition point locations, and weather at ignition. Modern ignition platforms already carry the telemetry. A sphere dispenser knows how many spheres it dropped and where. A drone logs its track. The data is generated and discarded. Capturing it on a stratified sample of 20 to 30 incidents per year, as a standard incident product, is the binding constraint on every research question in Part 13.

12. Instrument a subset of firing operations. Thermocouple arrays and fuel plots on a small number of burnout units per year, paired with free-burn controls on the same fire, produce the consumption measurement that does not exist. Fuel plots have been established and remeasured on active fires before. This is a field program, not a research revolution.

13. Build the retrospective layer. For a stratified sample of large fires since 2009, reconstruct firing operations from incident action plans, situation report narratives, infrared daily growth perimeters, the geodatabase, and structured interviews with assigned personnel. That method has been executed on one fire and at fire-season scale in another country. It works. It has simply not been funded here.

Part 11. Transparency: making the practice legible in the public record

The recommendations above make the practice measurable inside the agencies. This part makes it legible outside them, which is what determines whether research designs ever account for it.

14. Publish an annual intentional ignition report. One document, one table, three columns: acres ignited under a prescribed fire burn plan; acres ignited inside wildfire perimeters during suppression; and acres burned by free spread. The third column will be an estimate for years, and saying so is part of the point. The first column already exists. The second is the one that has never been published.

15. Caveat the national wildfire statistics. Until the second column exists, add one sentence to the national statistics page stating that reported acres include area intentionally ignited during suppression operations and that this component is not separately measured. That costs one sentence and is honest. The current presentation is not.

16. Publish the geospatial layer. Make the burnout layer, once it carries area, a public annual release on the same footing as fire perimeters. Perimeters are public. Retardant drop lines are a standard feature. There is no security or privacy rationale for withholding where fire was deliberately put on the ground, and the annual archives already publish evacuation and closure areas, which have a stronger claim to sensitivity.

17. Open the incident review database by tactic. The incident type value Firing Operation already exists in the review database. Make it filterable and countable from a public interface, and index attached documents rather than only record summaries. The agencies cannot learn from firing operation incidents they cannot enumerate, and neither can anyone else.

18. Require an ignition source statement in agency-funded fire research. Any study using burned area or burn severity inside wildfire perimeters should state whether ignition source was accounted for and, if not, that the analysis cannot distinguish firefighter-ignited from free-spreading area. This is a grant condition and a peer review norm, not a regulation. A model for the sentence already exists in the literature, where authors examining ownership effects on severity wrote that they were "unable to discern the effects of fire suppression activities and whether they varied by ownership." That sentence should become standard.

19. Report firing operations in post-fire public documents. Burned area emergency response reports, forest plan monitoring reports, and post-fire recovery plans are the documents communities and litigants actually read. None currently states how much of the fire was deliberately lit. Adding a paragraph converts an invisible practice into an accountable one.

20. Retain firing records permanently. Move firing records from the seven-year administrative category into the permanent incident history file. Seven-year destruction means that by the time a question is asked about a fire, the answer has been discarded. The retention schedule is an agency decision.

Part 12. What the research community should do

1. Treat ignition source as a covariate and say so when you cannot. Any study using satellite-derived burned area or severity inside wildfire perimeters is analyzing a mixed human and natural phenomenon while modeling it as natural. The minimum acceptable practice is a stated limitation, and journals should ask for it.

2. Stop treating burn severity indices as measures of what the hypothesis is about. Composite burn index and its remote sensing analogues are canopy-weighted, saturate at the top of their range, and classify with roughly 70 percent accuracy against field data in the forest types they were built for. They are not measures of forest floor consumption, soil heating, residence time, or energy release. The federal soils synthesis says so in its own words: duration of burning is critically important, and fire intensity "is not necessarily a good measure of the amount of energy transmitted downward into the soil."

3. Reanalyze existing data for refugia rather than for means. The cheapest decisive study in this review is a reanalysis. Take existing operations-mapped fire data and replace mean severity with three response variables: proportion of area with composite burn index at or near zero; unburned patch size distribution and total patch

perimeter; and within-unit variance of severity. Compare fired and unfired strata matched on terrain, fuels, prior fire history and fire weather day. If firing homogenizes, fired strata will show fewer and smaller unburned patches and lower severity variance, and a mean-effect design would never see it. No new field work required.

4. Do the consumption experiment. Pre-fire fuel loading from airborne laser scanning plus destructive plots measuring litter, duff depth to mineral soil, and woody debris by size class. Post-fire remeasurement in matched triplets: fired ground, free-burn ground on the same fire, and unburned control, matched on fuel type, slope, aspect, prior fire history and fire weather day. Report absolute consumption and fraction of pre-load by component, with attention to duff. Stratify by day versus night ignition and by heading versus backing configuration, to test the prediction that night backing burnout produces higher duff consumption and lower canopy severity than day firing on the same fire.

5. Study aerial ignition as a fire behavior phenomenon. Where in the roughly thirtyfold range of observed ignition densities does fire behavior change regime? Can dense simultaneous aerial ignition induce plume dominance or mass fire behavior, and under what conditions? How do the crown damage differences between strip-head and dot ignition scale to aerial dot patterns at operational spacing? What are the emissions consequences of ignition pattern? The most economical entry point is extending the existing physics-based ignition pattern simulations to aerial spacing geometries, which is an input change to a model already built and validated for exactly this question.

6. Get fire-fire interaction into the operational models. The governing review reported in 2011 that these effects "have yet to be included in any operational-fire models or decision support systems." The delivery technology has since quadrupled in rate. The planning tools used to design a firing operation cannot predict its outcome. Closing that is a modeling program, and it is overdue.

7. Replicate the Victorian quantification here. The method is published, the data sources have American counterparts, and the finding is the empirical anchor the American debate lacks. Pair it with fire spread simulation initialized at the moment of ignition to estimate the probability that each fired hectare would have burned unaided, which converts an accounting figure into a causal one.

8. Build the severity field assessment database. Leading practitioners called for it in 2014: instead of collapsing diverse fire effects into a single severity index, measure effects directly, and research the causal mechanisms linking conditions during the fire to outcomes. Twelve years on it does not exist. A database linking pre-fire conditions, in-fire behavior, ignition source and post-fire effects on the same ground is the infrastructure every question here depends on.

Part 13. A prioritized research and data agenda

Tier 1, immediate, inexpensive, no new field work

26. Compute and publish national burnout mileage and engagement outcomes from the existing quality-assured archive.
27. Reanalyze operations-mapped fire data for refugia, patch structure and severity variance rather than mean severity.
28. Text-mine archived situation report narratives for firing operation mentions, dates and locations, to build a first-pass national chronology.

29. Extend existing physics-based ignition pattern simulations to aerial dot spacing at operational densities.
30. Enumerate the incident review database by the Firing Operation incident type, and publish the list.

Tier 2, one to three years

31. Replicate the Victorian suppression firing quantification on a stratified American sample.
32. The paired consumption experiment, in at least two contrasting fuel types.
33. A controlled comparison of aerially ignited to hand-ignited fire effects, with replication and contemporaneous controls, on prescribed fire where design control is possible.
34. Sub-daily operational mapping of firing on a sample of incidents, as a standard incident product. This is the binding constraint on everything above it.
35. Old tree mortality in burnout units in long-unburned stands, given that duff consumption is the established predictor and residence time is set by ignition pattern.

Tier 3, program scale

36. Aerially ignited versus naturally spreading fire effects. This is the question that decides whether large-scale intentional ignition restores a fire regime or substitutes a different one, and it cannot be answered without items 6 and 9 first.
37. Emissions as a function of ignition source and pattern, with the inventories amended to carry the distinction.
38. Fire-fire interaction and coalescence physics incorporated into operational fire behavior models and decision support systems.
39. The severity field assessment database.

What Tier 1 alone would establish. How many miles of fire the United States deliberately lights each year, on how many incidents, and how often that fire held the line it was lit to hold. None of those three numbers has ever been published, and all three are computable from data the federal government already collected, quality assured, and released.

Part 14. Verification status

This review was assembled from the public record, and the verification pass is documented here so that a reader can weigh each claim.

Verified for this review against primary sources. The four NWCG firing curriculum quotations in Part 1, each extracted twice independently from the 2014 student workbook, including the missing article in the second. The ten glossary definitions, with status and steward committee, taken directly from the glossary rather than from any third-party compilation. The absence of any firing plan, go and no-go, documentation or resource protection requirement in the Red Book chapters examined. The prescribed fire signature requirements. The statutory compliance requirement in the prescribed fire planning guide and its 21 elements. The Exceptional Events Rule treatment of wildfire and prescribed fire. The emergency consultation provision and the Resource Advisor role. The retardant buffer and misapplication reporting duty. The Forest Service unmanned aircraft annual report figures for fiscal 2022, 2023 and 2024. The aviation annual report helitorch gel figures for calendar 2021 and 2022. The sphere defect lesson and its tech bulletin. The escaped aerial ignition prescribed fire review. And every number in Part 3, computed by direct query.

Corrected during verification. Two quotations circulating in earlier drafts were not exact. The risk management line is a sentence fragment and reads in full, "One thing a Firing Boss should always remember is, once firing is initiated it can be very difficult to 'put the genie back in the bottle.'" The firing pattern line reads "Heat production and flame lengths are managed via firing pattern and timing." In the sphere defect lesson, the comparison to a small caliber bullet describes the sound, not the fragments. The tech bulletin is dated October 26, 2023, despite its fiscal 2024 number, and the defect resides in the spheres rather than in the devices that deploy them. And the claim that ignition consumables are uncounted was wrong: the Forest Service publishes drone sphere counts and drone ignition acres. It does not publish them for helicopter delivery, and it does not split them between wildfire and prescribed fire.

Open items, with what each requires.

40. The 2014 firing curriculum remains publicly posted, but a blended replacement course was released September 11, 2025, and its content sits behind a training portal login. Whether the quoted language survives into the current version is unverified. Cite the 2014 workbook by date until someone with portal access confirms.
41. The Red Book chapter files served publicly are a 2023 edition while the current combined edition is dated May 2026. Chapter-level quotations should be re-pulled from the current combined file, and no page numbers are asserted here.
42. The location of the aerial ignition approval authority provision after the October 2025 revision, which moved unmanned aircraft content to a different standard.
43. Supplementary Table S2 of the Dixie Fire operations study, which contains the only per-category firing areas ever measured on an American fire. It is behind a publisher-robots policy and the paper's data availability statement directs requests to the authors. The paper is openly licensed. One email closes it.
44. The year covered by the national figures of approximately 758 aerial ignition hours and 134,381 acres. Confirmed not to be fiscal 2022, 2023 or 2024. The fiscal 2025 report is unpublished.
45. Whether the live incident feature service contains burnout polygons filtered from the public archive.
46. Deduplicated burnout length computed from geometry rather than from the hand-entered attribute, and burnout engagement outcomes, both of which require the published geodatabase. The host serving it was blocked by network policy for this review.
47. A complete enumeration of incident review products by the Firing Operation incident type, which requires the database filter in a browser.
48. Complete federal procurement totals for ignition equipment and consumables, which require a query capability not available here.
49. The scope statement of the current smoke management guidance, quoted here from its title rather than its text.
50. Verbatim text of two foundational duff mortality sources, cited here through a synthesis because the hosting servers were blocked.
51. Whether helitorch use is rising or falling beyond the two years of gel delivery figures. No agency document quantifies a trend, and no count of units in service exists.

One statement about method. The verified negatives in Part 5 are absence-of-hits results across three literature indexes, not exhaustive searches of grey literature, agency reports, or non-English literature. They are stated throughout as what they are: no study was found, with the search record given.

Sources

Suppression firing: practice, prevalence, effects

Ingalsbee, T. 2015. Ecological fire use for ecological fire management: managing large wildfires by design. Proceedings of the Large Wildland Fires Conference, RMRS-P-73:120-127. https://www.fs.usda.gov/rm/pubs/rmrs_p073/rmrs_p073_120_127.pdf

Simpson, H., Bradstock, R., Price, O. 2021. Quantifying the prevalence and practice of suppression firing with operational data from large fires in Victoria, Australia. Fire 4(4):63. https://doi.org/10.3390/fire4040063

Harris, L.B., Farris, C.A., Niziolek, C., Taylor, A.H. 2024. Severity of a megafire reduced by interactions of wildland fire suppression operations and previous burns. Environmental Research Letters 19:114070. https://doi.org/10.1088/1748-9326/ad8462

Harris, L.B., Drury, S., Farris, C.A., Taylor, A.H. 2021. International Journal of Wildland Fire 30:536-551. https://doi.org/10.1071/WF20163

Backer, D.M., Jensen, S.E., McPherson, G.R. 2004. Impacts of fire suppression activities on natural communities. Conservation Biology 18(4):937-946. https://www.frames.gov/catalog/3496

NWCG S-219 Firing Operations Student Workbook, NFES 001973, August 2014. https://training.nwcg.gov/dl/s219/s-219-sw.pdf

NWCG S-219 Firing Operations (Blended) released September 11, 2025. https://www.nwcg.gov/training/training-catalog-and-index/firing-operations-blended

Wildland Fire Suppression Tactics Reference Guide, 1996. https://www.coloradofirecamp.com/suppression-tactics/suppression-tactics-guide.pdf

NWCG glossary and standards

NWCG Glossary of Wildland Fire, PMS 205. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205

PMS 205, burning out. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/burning-out

PMS 205, backfire. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/backfire

PMS 205, backfiring. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/backfiring

PMS 205, suppression firing, status Archived. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/suppression-firing

PMS 205, indirect attack. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/indirect-attack

PMS 205, firing out. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/firing-out

PMS 205, aerial ignition. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/aerial-ignition

PMS 205, aerial ignition device. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/aerial-ignition-device-aid

PMS 205, plastic sphere dispenser. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/plastic-sphere-dispenser-psd

PMS 205, delayed aerial ignition devices. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/delayed-aerial-ignition-devices-daid

PMS 205, helitorch. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/helitorch

PMS 205, slopover. https://www.nwcg.gov/publications/pms205/nwcg-glossary-of-wildland-fire-pms-205/slopover

NWCG Standards for Aerial Ignition, PMS 501. https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms501.pdf

PMS 501 summary of changes, October 2025. https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms501-summary-of-changes.pdf

PMS 501 Appendix B, Helitorch Operations. https://fs-prod-nwcg.s3.us-gov-west-1.amazonaws.com/s3fs-public/publication/pms501-appendix-b-helitorch-operations.pdf

NWCG Standards for Fire Unmanned Aircraft Systems Operations, PMS 515. https://www.nwcg.gov/publications/pms515

NWCG Standards for Geospatial Operations, PMS 936, line symbology. https://www.nwcg.gov/publications/pms936/pms-936-symbology-line

PMS 936, Completed Burnout line feature. https://www.nwcg.gov/symbology/line/completed-burnout

PMS 936, Event Geodatabase and National Incident Feature Services. https://www.nwcg.gov/publications/pms936/event-geodatabase-national-incident-feature-services

Interagency Standards for Fire and Fire Aviation Operations, Red Book. https://www.nifc.gov/standards/guides/red-book

Red Book Chapter 16, Aviation Operations and Resources. https://www.nifc.gov/sites/default/files/redbook-files/Chapter16.pdf

Interagency Prescribed Fire Planning and Implementation Procedures Guide, PMS 484. https://nrfirescience.org/sites/default/files/InteragencyPrescribedFirePlanningProceduresGuide.pdf

National incident archive, queried for this review

NIFC Operational Data Archive feature services. https://services3.arcgis.com/T4QMspbfLg3qTGWY/arcgis/rest/services

National Incident Feature Service overview. https://wfigs-nifc.hub.arcgis.com/pages/nifs

Arkowitz, A., Ritter, S., Thompson, M.P., Young, J., Pietruszka, B., Calkin, D. 2025. Quality assured spatial dataset of wildfire containment firelines and engagement outcomes 2017 to 2024. Scientific Data. https://www.nature.com/articles/s41597-025-05208-0

Arkowitz et al. 2025 data archive. https://doi.org/10.2737/RDS-2025-0011

Gannon, B.M. et al. 2020. A geospatial framework to assess fireline effectiveness for large wildfires in the western USA. Fire 3(3):43. https://doi.org/10.3390/fire3030043

Aerial ignition: technology, standards, scale

DOI Office of Aviation Services, UAS aerial ignition and payload development briefing paper, August 2018. https://www.doi.gov/sites/default/files/uploads/doi_uas_aerial_ignition_and_payload_development_08_2018.pdf

DOI FY2018 UAS Use Report. https://www.doi.gov/sites/doi.gov/files/uploads/doi_fy_2018_uas_use_report.pdf

DOI FY2022 Interagency UAS Program Final Report. https://www.doi.gov/sites/default/files/fy22-interagency-uas-program-final-report-v232.2.pdf

DOI FY2023 Aviation Safety Summary and Annual Report. https://www.doi.gov/sites/default/files/documents/2024-05/fy23-doi-aviation-safety-summary-and-annual-report.pdf

DOI FY2024 Aviation Safety Summary and Annual Report. https://www.doi.gov/sites/default/files/documents/2025-05/fy24-doi-aviation-safety-summary-and-annual-report.pdf

USDA Forest Service UAS FY2022 Annual Report. https://www.fs.usda.gov/sites/default/files/fs-uas-report-fy22.pdf

USDA Forest Service UAS program page, annual reports. https://www.fs.usda.gov/managing-land/fire/aviation/uas

USDA Forest Service Aviation Annual Report, CY2021. https://www.fs.usda.gov/sites/default/files/2022-11/CY21-Aviation-Report.pdf

USDA Forest Service Aviation Annual Report, CY2022. https://www.fs.usda.gov/sites/default/files/2024-02/2022-Aviation-Report.pdf

USDA Forest Service, Igniting the future: technology and prescribed fire, May 21, 2026. https://www.fs.usda.gov/about-agency/features/igniting-future-technology-prescribed-fire

USDA Forest Service, Aerial ignition academy trains drone pilots, reduces risk. https://www.fs.usda.gov/inside-fs/delivering-mission/sustain/aerial-ignition-academy-trains-drone-pilots-reduces-risk

USDA Forest Service, Drones change the way forest fires are managed. https://www.fs.usda.gov/inside-fs/delivering-mission/sustain/drones-change-way-forest-fires-are-managed

Interagency UAS Program, aerial ignition. https://uas.nifc.gov/aerial-ignition

USFS Technology and Development, plastic sphere dispenser. https://www.fs.usda.gov/t-d/aerial_ign/plsphere/describe.htm

USFS Technology and Development, helitorch. https://www.fs.usda.gov/t-d/aerial_ign/helitorc/describe.htm

Simplex Helitorch Model 5400 technical data. https://www.fs.usda.gov/t-d/aerial_ign/helitorc/equip/simplex/data.htm

DART Aerospace, Premo Plastic Sphere Dispenser. https://dartaerospace.com/products/premo%C2%AE-plastic-sphere-dispenser

GAO-24-106924, Department of the Interior drone program. https://www.gao.gov/assets/gao-24-106924.pdf

USASpending, DOI Blanket Purchase Agreement 140D0423A0050. https://api.usaspending.gov/api/v2/awards/CONT_IDV_140D0423A0050_1406/

Aerial ignition and ignition pattern: effects research

Lawrence, B.L., Mundorff, K., Keith, E. 2023. The impact of UAS aerial ignition on prescribed fire: a case study in multiple ecoregions of Texas and Louisiana. Fire Ecology 19:11. https://doi.org/10.1186/s42408-023-00170-x

Craycroft, J., Schweitzer, C. 2024. Case study of UAS ignition of prescribed fire in a mixedwood on the William B. Bankhead National Forest, Alabama. Fire Ecology 20:33. https://doi.org/10.1186/s42408-024-00263-1

Finney, M.A., McAllister, S.S. 2011. A review of fire interactions and mass fires. Journal of Combustion 2011:548328. https://doi.org/10.1155/2011/548328

Bonner, S., Hoffman, C., Linn, R. et al. 2024. Forest structural complexity and ignition pattern influence simulated prescribed fire effects. Fire Ecology 20:82. https://doi.org/10.1186/s42408-024-00314-7

Molina, J.R., Ortega, M., Rodriguez y Silva, F. 2021. Fire ignition patterns to manage prescribed fire behavior. Journal of Environmental Management 302:114052. https://doi.org/10.1016/j.jenvman.2021.114052

Martin, R.M., Hamman, S.T. 2016. Ignition patterns influence fire severity and plant communities in Pacific Northwest prairies. Fire Ecology 12(1):88-102. https://doi.org/10.4996/fireecology.1201088

Resop, L., Demarais, S., Strickland, B.K., Iglay, R.B. 2024. Fire season matters for midstory hardwood control. Journal of Environmental Management 363:121297. https://doi.org/10.1016/j.jenvman.2024.121297

Knapp, E.E., Keeley, J.E. 2006. Heterogeneity in fire severity within early and late season prescribed burns. International Journal of Wildland Fire 15:37-45. https://doi.org/10.1071/WF04068

Smoke, emissions, and air quality

Urbanski, S.P. 2014. Wildland fire emissions, carbon, and climate: emission factors. Forest Ecology and Management 317:51-60. https://doi.org/10.1016/j.foreco.2013.05.045

Penland, R., Flanagan, S., Ellison, L. et al. 2025. The effect of combustion conditions on emissions of elemental carbon and organic carbon. ACS ES&T Air 2(10):2056-2070. https://doi.org/10.1021/acsestair.4c00300

Kreider, M.R., Urbanski, S.P., Fargione, J. 2026. Prescribed fire is unlikely to reduce net PM2.5 emissions in most locations. PNAS 123(28):e2613722123. https://doi.org/10.1073/pnas.2613722123

EPA, Exceptional Events Guidance: Prescribed Fire on Wildland, August 2019. https://www.epa.gov/sites/default/files/2019-08/documents/ee_prescribed_fire_final_guidance_-_august_2019.pdf

40 CFR 50.14, Treatment of air quality monitoring data influenced by exceptional events. https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-50/section-50.14

NWCG Smoke Management Guide for Prescribed Fire, PMS 420-3. https://www.nwcg.gov/publications/pms420-3

Balch, J.K. et al. 2022. Warming weakens the night-time barrier to global fire. Nature 602:442-448. https://doi.org/10.1038/s41586-021-04325-1

Old growth, large trees, and duff

Hood, S.M., Varner, J.M., van Mantgem, P., Cansler, C.A. 2018. Fire and tree death: understanding and improving modeling of fire-induced tree mortality. Environmental Research Letters 13:113004. https://doi.org/10.1088/1748-9326/aae934

Varner, J.M. III, Hiers, J.K., Ottmar, R.D., Gordon, D.R., Putz, F.E., Wade, D.D. 2007. Overstory tree mortality resulting from reintroducing fire to long-unburned longleaf pine forests: the importance of duff moisture. Canadian Journal of Forest Research 37(8):1349-1358. https://doi.org/10.1139/X06-315

Hood, S.M. 2010. Mitigating old tree mortality in long-unburned, fire-dependent forests: a synthesis. RMRS-GTR-238. https://research.fs.usda.gov/treesearch/35004

Southern Fire Exchange. Reintroducing fire into long-unburned pine stands. https://southernfireexchange.org/wp-content/uploads/2018-4.pdf

Dixon, D.J., Das, A.J., Dong, X. et al. 2026. Previous prescribed burns saved thousands of ancient sequoias during historically unprecedented wildfires. Nature Communications 17:8558. https://doi.org/10.1038/s41467-026-75418-6

Amphibians, riparian, aquatic

USFWS species profile, Sierra Nevada yellow-legged frog. https://www.fws.gov/species/sierra-nevada-yellow-legged-frog-rana-sierrae

Final listing rule, foothill yellow-legged frog distinct population segments, 88 FR 59698. https://www.federalregister.gov/documents/2023/08/29/2023-17675/

Critical habitat designation, foothill yellow-legged frog, January 14, 2025. https://www.federalregister.gov/documents/2025/01/14/2024-31757/

Halstead, B.J., Kleeman, P.M., Rose, J.P. 2024. Using structural causal modeling to infer the effects of wildfire on foothill yellow-legged frog occurrence. Journal of Fish and Wildlife Management. https://doi.org/10.3996/JFWM-24-037

Unburned habitat essential for amphibian breeding persistence following wildfire. 2024. Global Ecology and Conservation 57:e03389. https://doi.org/10.1016/j.gecco.2024.e03389

Hossack, B.R., Pilliod, D.S. 2011. Amphibian responses to wildfire in the western United States. Fire Ecology 7(2):129-144. https://doi.org/10.4996/fireecology.0702129

USDA Forest Service. Record of Decision, Nationwide Aerial Application of Fire Retardant on National Forest System Land, 2011. https://www.fs.usda.gov/sites/default/files/media_wysiwyg/wfcs_rod_12_15_11_0.pdf

USDA Forest Service. Ecological Risk Assessment of Wildland Fire-Fighting Chemicals, December 2025. https://www.fs.usda.gov/rm/fire/wfcs/documents/NONCONFIDENTIAL%20EcoRA-Retardants-Dec2025.pdf

Dwire, K.A., Kauffman, J.B. 2003. Fire and riparian ecosystems in landscapes of the western USA. Forest Ecology and Management 178:61-74. https://doi.org/10.1016/S0378-1127(03)00053-7

Pettit, N.E., Naiman, R.J. 2007. Fire in the riparian zone. Ecosystems 10(5):673-687. https://doi.org/10.1007/s10021-007-9048-5

Bendix, J., Commons, M.G. 2017. Distribution and frequency of wildfire in California riparian ecosystems. Environmental Research Letters 12(7):075008. https://doi.org/10.1088/1748-9326/aa7087

Reeves, G.H., Bisson, P.A., Rieman, B.E., Benda, L.E. 2006. Postfire logging in riparian areas. Conservation Biology 20(4):994-1004. https://doi.org/10.1111/j.1523-1739.2006.00502.x

Stone, K.R. et al. 2010. Fuel reduction management practices in riparian areas of the western USA. Environmental Management 46(1):91-100. https://doi.org/10.1007/s00267-010-9501-7

Type conversion, reburn, soils

Coop, J.D. et al. 2020. Wildfire-driven forest conversion in western North American landscapes. BioScience 70(8):659-673. https://doi.org/10.1093/biosci/biaa061

Coppoletta, M., Merriam, K.E., Collins, B.M. 2016. Post-fire vegetation and fuel development influences fire severity patterns in reburns. Ecological Applications 26(3):686-699. https://doi.org/10.1890/15-0225

Davis, K.T. et al. 2019. Wildfires and climate change push low-elevation forests across a critical climate threshold for tree regeneration. PNAS 116(13). https://doi.org/10.1073/pnas.1815107116

Syphard, A.D., Brennan, T.J., Keeley, J.E. 2019. Extent and drivers of vegetation type conversion in southern California chaparral. Ecosphere 10(7):e02796. https://doi.org/10.1002/ecs2.2796

Neary, D.G., Ryan, K.C., DeBano, L.F., eds. 2005. Wildland fire in ecosystems: effects of fire on soil and water. RMRS-GTR-42-vol.4. https://www.fs.usda.gov/rm/pubs/rmrs_gtr042_4.pdf

Certini, G. 2005. Effects of fire on properties of forest soils: a review. Oecologia 143(1):1-10. https://doi.org/10.1007/s00442-004-1788-8

Parsons, A. et al. 2010. Field guide for mapping post-fire soil burn severity. RMRS-GTR-243. https://research.fs.usda.gov/treesearch/36236

Fire refugia and severity measurement

Kolden, C.A. et al. 2012. Mapped versus actual burned area within wildfire perimeters. Forest Ecology and Management 286:38-47. https://www.frames.gov/catalog/13305

Meddens, A.J.H. et al. 2018. Fire refugia: what are they, and why do they matter for global change? Ecosphere 9(2):e02029. https://doi.org/10.1002/ecs2.2029

Platt, E., Chapman, T., Balch, J.K. 2024. Environmental Research Letters 19:014044. https://doi.org/10.1088/1748-9326/ad11bf

Krawchuk, M.A. et al. 2016. Ecosphere 7(12):e01632. https://doi.org/10.1002/ecs2.1632

Meigs, G.W. et al. 2020. Canadian Journal of Forest Research 50:636-647. https://doi.org/10.1139/cjfr-2019-0406

Keeley, J.E. 2009. Fire intensity, fire severity and burn severity: a brief review and suggested usage. International Journal of Wildland Fire 18:116-126. https://doi.org/10.1071/WF07049

Morgan, P. et al. 2014. Challenges of assessing fire and burn severity. International Journal of Wildland Fire 23:1045-1060. https://doi.org/10.1071/WF13058

Kolden, C.A., Smith, A.M.S., Abatzoglou, J.T. 2015. Limitations and utilisation of Monitoring Trends in Burn Severity products. International Journal of Wildland Fire 24(5). https://doi.org/10.1071/WF15082

Kreider, M.R. et al. 2024. Fire suppression makes wildfires more severe and accentuates impacts of climate change and fuel accumulation. Nature Communications 15:2412. https://doi.org/10.1038/s41467-024-46702-0

Incident data systems, safety, and oversight

ICS-209 form. https://www.nifc.gov/sites/default/files/NICC/2-Predictive%20Services/Intelligence/ICS%20209%20Fillable%20PDF%20Form.pdf

2023 ICS-209 Program User's Guide. https://www.nifc.gov/sites/default/files/document-media/2023_ICS-209_User_Guide.pdf

NIFC wildfire statistics. https://www.nifc.gov/fire-information/statistics/wildfires

FPA-FOD sixth edition metadata. https://data.fs.usda.gov/geodata/edw/edw_resources/meta/S_USA.Fire_FPA_FOD_6th_Fires.xml

MTBS fire mapping FAQ. https://www.mtbs.gov/faq/fire-mapping

WFDSS help, about decisions. https://wfdss.usgs.gov/wfdss_help/WFDSS_Help_about_decisions.html

NARA-approved USDA Forest Service fire records schedule. https://www.archives.gov/files/records-mgmt/rcs/schedules/departments/department-of-agriculture/rg-0095/n1-095-05-002_sf115.pdf

Wildland Fire Lessons Learned Center, Incident Review Database. https://lessons.wildfire.gov/search-irdb

Quarry Fire Aerial Ignition Devices Rapid Lesson Sharing, October 5, 2023. https://lessonslearned-prod-media-bucket.s3.us-gov-west-1.amazonaws.com/s3fs-public/2023-12/Quarry%20Fire%20Aerial%20Ignition%20Devices%20RLS.pdf

Interagency Aviation Tech Bulletin IA TB 24-01, October 26, 2023. https://www.doi.gov/sites/default/files/iatb-2024-01.pdf

Brittle Escaped Prescribed Fire Facilitated Learning Analysis, 2021. https://lessonslearned-prod-media-bucket.s3.us-gov-west-1.amazonaws.com/s3fs-public/2023-07/Brittle%20Escaped%20Prescribed%20Fire%20FLA.pdf

Sam Houston National Forest prescribed fire helicopter accident fatality, Facilitated Learning Analysis. https://lessonslearned-prod-media-bucket.s3.us-gov-west-1.amazonaws.com/s3fs-public/2023-02/Sam%20Houston%20FLA%20Final%20Updated%204222020.pdf

USDA Forest Service National Prescribed Fire Program Review, September 8, 2022. https://www.frames.gov/documents/usfs/USFS_20220908_National-Prescribed-Fire-Program-Review.pdf

GAO-24-106239, Forest Service prescribed fire program. https://www.gao.gov/assets/gao-24-106239.pdf

GAO-15-772, Wildland Fire Management. https://www.gao.gov/products/gao-15-772

GAO-25-108589, Wildfire Management technologies. https://files.gao.gov/reports/GAO-25-108589/index.html

50 CFR 402.05, emergency consultation. https://www.ecfr.gov/current/title-50/chapter-IV/subchapter-A/part-402/subpart-A/section-402.05

Resource Advisor's Guide for Wildland Fire. https://www.umt.edu/media/wilderness/toolboxes/documents/fire/NWCG_READ_Guide_2004.pdf

Post-Fire Line Officer Guide, 2025. https://wfmrda.nwcg.gov/sites/default/files/docs/Line_Officer/Agency_Admin_Toolbox/PostFire_LineOfficerGuide_2025.pdf

Policy

Guidance for Implementation of Federal Wildland Fire Management Policy, February 13, 2009. https://www.doi.gov/sites/doi.gov/files/uploads/2009-wfm-guidance-for-implementation.pdf

Forest Service Manual 5130, Amendment 5100-2020-1. https://www.usda.gov/sites/default/files/guidance-documents/ForestService.Manual%205100%205130%20Wildfire%20Response.pdf

Thompson, M.P., O'Connor, C.D., Gannon, B.M. et al. 2022. Potential operational delineations. Fire Ecology 18(1):17. https://doi.org/10.1186/s42408-022-00139-2

RMRS, POD Boundaries and Fuel Breaks are not Synonymous. https://research.fs.usda.gov/rmrs/understory/pod-boundaries-and-fuel-breaks-are-not-synonymous-considerations-potential

Secretary of the Interior, 2026 Wildland Fire Management Direction, April 8, 2026. https://cdn.ymaws.com/www.azfirechiefs.org/resource/resmgr/2026/email2026/wildland-fire_management_dir.pdf

Secretary of Agriculture, 2026 Wildfire Readiness Memorandum, April 29, 2026. https://www.usda.gov/about-usda/news/press-releases/2026/04/29/secretary-agriculture-issues-2026-wildfire-readiness-memorandum-ahead-active-fire-season

Chief's Wildfire Letter of Intent, 2025. https://www.fs.usda.gov/inside-fs/leadership/wildfire-letter-intent-2025

Chief's Fire Letter of Intent, 2026. https://www.fs.usda.gov/inside-fs/leadership/2026-fire-letter-intent