National Park Service

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Fire and Aviation Management

Grand Canyon National Park / Northern Arizona Fire Ecology Annual Report Calendar Year 2024

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Top left: Hiking to plots with the Southern Colorado Plateau Network Inventory & Monitoring crew
Top center: Monitoring weather and fire behavior during the Cape Final Prescribed Fire
Top right: Measuring surface fuels at Walnut Canyon
Bottom center: The Grand Canyon from Point Sublime
(photos by Li Brannfors)

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A. Background

Interagency Standards for Fire and Fire Aviation Operations (DOI & USDA 2025), defines fire preparedness as the state of being ready to respond to wildfires based on identified objectives and is the result of activities that are planned and implemented prior to fire ignitions.
Preparedness requires, amongst other things:
- *Identifying necessary firefighting capabilities;*
- *Implementing coordinated programs to develop those capabilities;*
- *A continuous process of developing and maintaining firefighting infrastructure;*
- *Predicting fire activity;*
- *Implementing prevention activities;*
- *Identifying values to be protected;*
- *Hiring, training, equipping, prepositioning, and deploying firefighters and equipment;*
- *Reviewing preparedness plan compliance;*
- *Correcting deficiencies; and*
- *Improving planning and operations.*

Preparedness activities focus on developing response capabilities that will result in safe, effective, and efficient fire operations aligned with risk-based fire management decisions.

In accordance with the Red Book, the National Park Service implements an adaptive management approach to fire preparedness (RM 18):

Adaptive management is a system of management practices based on clearly identified objectives in conjunction with monitoring to determine if management actions are meeting those objectives. In cases where objectives are not being met, adaptive management is intended to facilitate management changes that will ensure that desired outcomes are met or to facilitate re-evaluation of the desired outcomes. As described in the Fuels Management chapter in RM 18, adaptive management is an iterative process requiring continual evaluation of results to determine whether the ongoing treatments are appropriate or whether they need modification. Monitoring data provide the basis for adaptive management by allowing managers to determine whether objectives are being met or whether undesired effects are occurring.

The National Park Service (NPS) Division of Fire and Aviation Management relies on science and both short-term and long-term monitoring to inform adaptive management efficient and effective, and continuously improving fire management programs and activities at park units. As outlined in RM 18, communicating the results and meaning of data on fire behavior and effects is a crucial component of adaptive management and fire preparedness. Fire preparedness, adaptive management, and policies, standards, and responsibilities for monitoring are described in Chapter 8 of Reference Manual 18. The NPS Fire Ecology Program is responsible for the collection, analysis, and interpretation of fire behavior and fire effects data for program evaluation, risk assessment, and informed decision making.

This annual report is intended to partially fulfill reporting requirements for the Fire Ecology Program and does not constitute a complete analysis of any NPS fire management program or activity. Additional interpretation and reporting can be found in previous annual reports at NPS DataStore or by contacting the author(s) of this report.

B. Executive Summary

This section is intended as a summary of findings & recommendations, from 2024 work.

Key Findings

- This year the Fire Ecology program took the initial step towards modernizing graphical and statistical summaries of restoration objectives (built on the foundation of queries used for the traditional analyses, without having the database improvements being sought and described below). Results of this effort for each ponderosa pine habitats (PIPO; PIPN; PIAB) can be found on **pages 13-21**; traditional tabular analyses appear on **pages 24-26**.
- North and South Rim ponderosa pine areas are successfully meeting historical objectives for large ponderosa and conifer retention (PIPO & PIPN; respectively). Areas of ponderosa pine with white fir encroachment (PIAB) show more mixed results, suggesting that longer-term this objective will need additional attention.
- Desired objectives for keeping overall densities of the next generation of pole-sized trees within reasonable limits for fuel loadings and to ensure ongoing forest resources have been initially very successful, but are showing some downward (PIPN) or bi-polar trends (with some plots having far too many and others potentially too few; PIPO; PIAB).
- Fires are having the desired effect on immediate post-fire fuel loadings, with some rebounding 5-10 years post-fire suggesting GRCA's fire intervals have been appropriately reducing fire risk (PIPO, PIPN, PIAB).
- Data from mixed-conifer and pinyon-juniper areas <u>is not currently being analyzed</u> due to ongoing challenges with separate national databases. Correcting this situation is urgently needed & addressed under recommendations.
- Significant progress was made updating QA/QC for program data, meeting equivalencies from FFI QA/QC process while adding previously unincorporated error checks. Custom code has been created for the suite of parks, plots, and protocols which Grand Canyon manages, including FMH, I&M, and RAP plots with queries for the range of protocols related to trees, seedlings, shrubs, herbs, and fuel loading. Code has also been developed in a way that can be easily customized for other NPS Fire Ecology programs and has been shared with other programs via the new FFI + R Working Group, which is managed by our Asst Lead Monitor.
- Program staff served as fire resources and support for multiple wildfires, prescribed burns, and direct and support roles for firefighting, preparedness, and risk reduction activities on the ground, detailed on **pages 9-11** and in **Appendix A**.

Programmatic Challenges & Improvements for 2024

- See **pages 6-14** for additional details.
- **Fire severity tracking stalled:** Fire severity classification & tracking was stalled due to incompatibilities with staffing levels and MTBS processes. Succinct analysis of data previously collected and carefully curated by this program identified a solution. Validation & calibration of remote sensing data is still necessary, but greatly reduced.

- Several challenges to efficient and effective fire program operation were identified and addressed during 2024. Solutions were identified and pursued. Many solutions are currently on hold, awaiting additional funding review guidelines, process, and timelines.
    - **Prior severe fire impacts:** Large North Rim areas were previously impacted by multiple severe fires, degrading services & resources valuable to people and wildlife (water, visitor experience, wildlife habitat), increasing fire risk due to dense seas of continuous, prickly, small diameter fuels, and requiring intervention. Program data was used to evaluate risk, design a solution, and obtain implementation funding. This project may not be able to absorb funding delays, because of funding expiration dates & /biological constraints.
    - **Modernizing & streamlining workflow**: (e.g. preparing data for integration into the R and R Studio suite and interfacing with GIS, etc.) is needed urgently to inform preparedness across the landscape. GRCA requested assistance (internal guidance & funding for external expertise), to urgently & efficiently modernize program capabilities. GRCA is standing by for decisions on assistance.
    - **Identifying innovative strategies for shifting fire conditions:** To address shifting baseline conditions that change fire behavior and other risk factors, identification of innovative strategies and their appropriate uses is direly needed. The Fire Ecology Program outlined the associated tasks and submitted a proposal for completing the tasks efficiently and urgently. Funding pause effects on this project remain unclear.
    - **Addressing data gaps:** Existing studies were used to identify gaps in knowledge regarding prescription designs that could lead to unintended effects and/or unexpected risk (such as how they interact with wind speeds & plant water stress, two crucial factors in fire behavior). A project to address these knowledge gaps for accurate fire preparedness was designed, and proposal submitted.

Major Recommendations

- Effectively and efficiently **modernizing and streamlining workflow** & data analyses for this program is essential to fire preparedness, flexible & adaptive management, and informed risk assessment. Without funding for the requested external assistance, the Fire Ecologist, and potentially other program staff, will need to spend increased amounts of time on this urgent task reducing their ability to contribute in other areas. This task is essential to understanding changes in baseline conditions affecting risk to people, communities, local businesses, and resources, so it will be prioritized above other tasks within existing workloads.
    - In particular, when the Fire Ecology program was created mixed-conifer and pinyon juniper ecosystems were not a high risk concern, did not have historically-appropriate, short-interval fire regime needs like the ponderosa pine ecosystems, and therefore had no established programmatic objectives and corresponding analyses and reporting. However, because baseline drought, wind, and other conditions have changed, these ecosystems are now under stress, are at risk, are a major focus of fire preparedness and response, and require programmatic objectives appropriate to the situation. Data from mixed-conifer and pinyon-juniper from these areas also resides in separate national databases from data on

other ecosystems, with separate protocols and protocol differences over time – factors that must all be appropriately dealt with to ensure risk management decisions are sound. This situation represents a huge gap in our understanding of risk across the landscape at GRCA. It is imperative that both current data and the backlog of data be merged with our other data and be folded into the modernization and streamlining of workflow and analysis, risk assessments and fire preparedness are sound going forward.

- Continue to explore options for **addressing data gaps**, particularly if impacted by funding pauses. This is crucial to accurate risk assessments & informed preparedness. E.g., studies on VPD & fire behavior / risk need updating with soil moisture interactions.
- If funding pauses impact the project to **identify innovative strategies**, this task should be prioritized above other tasks within existing workloads, due to its urgent & crucial nature.
- Continue with methods for **fire severity classification and tracking** developed in 2024. Develop a schedule for updates and ground validation & calibration of remote data.

C. Fire Ecologist Accomplishments & Workload

In February 2024, Dr. Lisa Handforth came aboard as the Fire Ecologist for the Northern Arizona/Grand Canyon (GRCA) Fire Ecology program, filling a crucial position that has had a good deal of challenges over recent years. This provided a firm foundation for GRCA to reformat and update its Fire Management Plan, resolve challenges with the fire severity classification system that have posed challenges to the fire program's risk assessments, consultations and duties under reduced staffing, and identify and address several areas needing innovation and a path forward within the big picture of the GRCA Fire Ecology Program. A breakout and summary of many of the Fire Ecologist's accomplishments, tasks, and focus areas for 2024 can be found in **Appendix A**, **Table A-2**. Here we will focus on big picture areas where the Fire Ecologist found ways to move the program forward during 2024.

Table 1 summarizes several challenges or gaps in moving the GRCA fire program forward that presented themselves this past year, and some of the actions taken by the Fire Ecologist to resolve or innovate in those areas, including identification of the challenges, identification of creative and feasible solutions, and initial implementation of solutions, in some cases including applications for external collaborations and funding. Each challenge is described in more detail in **Appendix B** as well. Objectives successfully achieved are represented by green check marks (√). Objectives not yet successfully achieved or whose achievement remains uncertain are represented by a red question mark (**?**).

Table 1: Challenges Encountered During 2024 and Actions Taken in Response

Challenge Encountered	Crucial Issue Because	Action Taken	External Assistance Sought	External Funding Awarded	Resolution Achieved
Fire severity tracking stalled (and overdue).	Fire program lacked information about past fire severity / effects to make decisions about managing fuels, resources, and fires.	Utilized program data to create method for severity classification that requires less frequent calibration.	Sought and received input and assistance from IMR Fire Ecologist and Fire GIS Specialist to develop new statistical methodology.	None needed. √	New methodology accepted by USFWS and GRCA and now in use. Will require intermittent ground calibration, for which a schedule needs to be developed. √
Prior severe fire impacts were unaddressed. Repeated severe fires reduced the value & function of large areas of the North Rim, precluding effective fire fighting, and reducing value for visitors, snowpack/water, and wildlife. Severity and size of areas makes recovery without intervention highly unlikely.	Firefighting would be nearly impossible in these areas, the status of these areas conflict with ongoing fire preparedness and services needed from the ecosystem for people, wildlife and more (e.g. water supplies).	Identified monitoring plots affected. Program data to determine intervention required. Demonstrated power of the data to ensure future burn severity impacts can be identified & mitigated & park can maintain fire preparedness.	Submitted a modification to the Fuller Fire BAER report, and submitted a proposal for funding to strategically remediate the areas and incorporate innovative, evidence-based techniques to ensure success.	GRCA was awarded funding. √	Funding was paused before project could be awarded & project award has been delayed. We have been awaiting new review guidelines, timeline, and process. We are hopeful that the project can now be awarded given the exemptions granted for wildfire preparedness activities. ?
Modernizing & streamlining workflow. GRCA has extensive Fire Ecology program data on fire behavior, effects, fuels and resources. However, this data lacks broad analysis on a variety of crucial issues. Correcting this requires modernizing and streamlining the database(s) and analyses.	Adaptive management of resources and fire cannot proceed without up-to-date information. Fire fighting, prescriptions and other management actions will be inappropriate to current conditions if not informed by data. This increases risk and decreases success and is inefficient.	During 2024 the Fire Ecologist outlined program data, its application to urgent challenges, and existing and future desired workflows (see **Appendix B**) for regional and national database and fire program leads.	Requested assistance and provision of internal database tables and join structure from database managers, for use in modern analysis software. Requested assistance from R and analysis experts, submitted NRPP (Natural Resource Protection Program) funding request.	At this time there are no updates regarding whether NRPP funding will be available generally or for this project. We are working with Grand Canyon Conservancy (GCC) to evaluate alternatives. ?	Awaiting response from regional and national leaders regarding request for existing database tables and join structure. Given current funding restrictions, we recommend reserving more of Fire Ecologist's time for these tasks, which are crucial to fire preparedness, efficiency and effectiveness. ?

Challenge Encountered	Crucial Issue Because	Action Taken	External Assistance Sought	External Funding Awarded	Resolution Achieved
Addressing data gaps is crucial to fire preparedness. Knowledge regarding fuel and plant interactions to maintain resiliency in the face of increasing drought has advanced. An assessment of where and how this program can integrate that knowledge is overdue due to staff and resource limitations.	New types of data, often inexpensive, can be collected to better inform fire behavior and management. Without a review of these knowledge gaps, understanding of how treatments and wildfire will interact with shifting baseline conditions will lead managers to incorrect risk assessments and fire management decisions.	Evidence gaps were outlined, and a project to address them and test which measures are the most crucial for advancing the program was identified as a companion to at least one treatment.	A proposal was collaboratively developed and submitted as a Reserve Fund Research Request to address these gaps.	Awaiting funding updates and other avenues to address this challenge. ?	Standing by to better understand outlook for funding and evaluating other ways to complete this task necessary to inform preparedness. Working with GCC to find alternative ways of achieving this goal. ?
Identifying innovative management strategies for shifting baseline conditions, and their effects on fire behavior and severity, prescribed fire windows, and drought forecasts had not yet started in earnest at GRCA. An Integrated Fire Management approach will be needed to manage fire risk, integrating a wider variety of innovative and traditional approaches.	As prescribed burn windows shift, and drought conditions increase wildfire extent & severity, innovative, integrated strategies will be needed. What worked before may no longer yield expected results – a lack of fire preparedness and potentially disastrous results could emerge from failing to integrate a wider variety of integrated management strategies.	Presented the challenge to SRM and GRCA fire programs to obtain consensus. Submitted proposal for a SIP (Scientist in the Park) intern to assist with the needed tasks.	Outlined needed tasks and process, incorporating existing NPS national efforts. Worked with Science & Resource Management (SRM) to submit proposals to obtain external funding from GCC and the SIP program.	Both GCC & SIP funding awarded. √	This project has been held-up in funding pauses and reviews. The SIP program does not seem able to provide an intern within the needed timeline (this summer). Thanks to efforts on the part of GCC, we expect to still be able to fill this position and complete this task, we are currently standing by for final confirmation. ?

D. Fire Effects Accomplishments & Workload

In 2024, the Northern Arizona/Grand Canyon (GRCA) Fire Ecology program met both planned and unplanned challenges, accomplishing a wide variety of work with internal and external partners as well as providing support to multiple fires and local planning efforts. A total of 68 fire effects plots were read at Grand Canyon National Park and Walnut Canyon National Monument (WACA), prescribed fires and managed wildfires burned on both South and North Rims, relationships with resource staff at multiple parks were fostered, and programmatic duties were executed by the Fire Ecology program in the absence of key leadership positions within the Branch.

Staffing stability returned to the Fire Ecology program with all three permanent positions filled beginning in late January. Three seasonal Fire Effects crewmembers were hired, including the return of a 2023 crewmember to provide an additional level of expertise and leadership. The Lead detailed for 2.5 months over the winter and spring to the Colorado Front Range-Northwest Colorado/Rocky Mountain (ROMO) Fire Ecology program to assist with program assessment, seasonal hiring, and new staff onboarding. By early May, seasonals had onboarded and all permanent staff were in place at GRCA, ushering in a season of full staffing without change for the first time since 2016.

Monitoring went smoothly and efficiently with complete staff, returning knowledge, and few local fires. Within the 68 total plots visited (**Tables 2 & 2A**), 30 Fire Monitoring Handbook (FMH), 1 Inventory and Monitoring (I&M) pinyon-juniper, and 24 I&M mixed conifer plots were read at GRCA; along with 13 combination FMH-I&M plots visited at Walnut Canyon National Monument (WACA). All FMH and I&M data were entered and checked, with only the current year's shared tree I&M data remaining due to their program's rigorous QAQC process. The crew assisted other divisions and diversified their experience by working with archeology, vegetation, and wildlife staff on several occasions. In return, staff from other GRCA work units joined the Fire Effects crew to learn about our operation and help read plots multiple times.

Our yearly partnership with the Southern Colorado Plateau Network (SCPN) I&M program reached a new height, collecting data together on all I&M plots scheduled in 2024 at both GRCA & WACA. Collaborative measurements of 37 existing upland forest plots were performed by both crews, and 1 plot was individually read by GRCA Fire Effects staff after it unexpectedly burned in the Mescalero Fire on the South Rim. Virtually seamless data sharing became possible and redundancy was reduced by again gathering tree data exclusively in the I&M database, facilitated by new data manipulation capabilities with R software via SCPN Ecologist Megan Swan and CSV files with the GRCA FEAT-Firemon Integrated (FFI) database. Collecting these data on a pre- and post-disturbance schedule similar to FMH protocols continues to facilitate comparable landscape-scale, long-term monitoring of forest structure, fuel loading, and herbaceous species diversity across all forested vegetation types. This sharing of knowledge and skills, collaboration, and relationship building are high values worth perpetuating.

For the eleventh straight season, 100 percent of Grand Canyon field data were collected on tablets and managed electronically, enhancing efficiency. New challenges emerged when IT security updates prevented access to the program's standard Excel data collection spreadsheets. Despite this roadblock, the crew was able to use their knowledge of electronic data collection to adapt the Excel template into Google Sheets, which is an openly available spreadsheet program. The crew successfully collected electronic data using mobile devices at GRCA and WACA during the entire field season. Additional efficiencies to the data collection process were developed using the R programming software, which is growing in importance in the Fire Ecology program. Code was developed in R to improve file conversion for data import into FFI and supplement quality control/quality assurance (QAQC) capabilities. This knowledge continues to be expanded by sharing electronic data collection discoveries with additional programs, including the Yellowstone, Klamath/Redwood, and Southern Sierra Nevada/Sequoia-Kings Canyon Fire Ecology groups.

Interspersed with plot data collection at Grand Canyon and other parks was a subdued prescribed and managed fire season. Fire Ecology staff provided Resource Advisor (READ) assistance to the park's Fire Archeologist to prep multiple burn units and primary Fire Effects Monitor (FEMO) support on 2 prescribed burns on the North Rim and USFS North Kaibab Ranger District. Fire assignments off-district also were dedicated to READ work with the Fire Archeologist, ranging across New Mexico, central Arizona, northern California, and Idaho, providing additional experience away from Grand Canyon for the Assistant and all crewmembers. One individual was recommended for READ certification based on the diversity and quality of their work this season. Overtime work boosted Severity staffing, multiple initial attacks & sizeups, prescribed fire prep work, and hand thinning projects for North Zone Fire Management (USFS North Kaibab Ranger District-Kaibab National Forest & NPS North Rim-Grand Canyon National Park). In total, Ecology staff worked on 12 incidents and Severity, prep, or READ surveys over 89 total operational periods and completed 4 different NWCG training classes, continuing our commitment to provide valuable support to operational fire activities while offering invaluable experience to our employees for continuing careers in wildland fire.

A flaming stump meets its match on the Hollow Tank Fire (photo by NPS)

Table 2: 2024 Grand Canyon National Park Fire Effects Plots Established

Rim	Code	Monitoring Unit	Plot Type	Total Plots[1]	Years Data Collected (start-end)	Annual Total (2024)	2024 Collections		
							Install / Pre-burn	Post - Burn	Years 1 - 20
South	PIPO	Ponderosa Pine	FMH - Forest	41	1990 - 2024	7			7
South	PIED[2]	Pinyon-Juniper Woodland	FMH - Forest	17	1990 - 2023	0			
South	I&M PJ	Pinyon-Juniper	I&M[3]	30	2021 - 2024	1		1	
South		Moqui Rx	RAP[4]	5	2008 - 2011	0			
South		Picnic Rx	RAP[4]	10	2008 - 2011	0			
South		Quarry Rx	RAP[4]	10	2008 - 2011	0			
South		Tusayan Pueblo (Thinning)	RAP[4]	20	2023	0			
North	PIPN	Ponderosa Pine	FMH - Forest	30	1992 - 2024	14			14
North	PIAB	Ponderosa Pine with White Fir Encroachment	FMH - Forest	27	1993 - 2024	6			6
North	PIEN	Rocky Mountain Subalpine Conifer	FMH - Forest	17	1993 - 2024	3	2		1
North	GRIN	Grassland Interior	FMH - Brush	10	2001 - 2002	0			
North	GRED	Grassland Edge	FMH - Forest	6	2001	0			
North	I&M Mix	Mixed Conifer	I&M[3]	46	2010 - 2024	24	13		11
North		Fawn Spring Rx[5]	RAP[4]	20	2010 - 2022	0			
North		Highway 67 Rx[5]	RAP[4]	20	2015 - 2022	0			
North		Range Rx	RAP[4]	20	2008 - 2014	0			
North		Spring Canyon Rx[5]	RAP[4]	20	2010 - 2022	0			
North		Thompson Rx	RAP[4]	20	2009 - 2017	0			
North		Burnt Corral-NKRD	RAP[4]	50	2015	0			
North		Tipover Rx-NKRD	RAP[4]	40	2013 - 2022	0			
North		Walla Valley Rx	RAP[4]	6	2008	0			
Total				**485**		**55**	**15**	**1**	**39**

[1] Total Plots includes all permanent plots (FMH, RAP, or I&M) installed to date within a monitoring unit/type.
[2] PIED monitoring type reads were discontinued in 2000 & resurrected in 2021 for protocols of interest.
[3] Fuel and tree data collected to add to data collected by I&M crews.
[4] Rapid Assessment Plots; Pilot sampling.
[5] While RAP plots were installed with specific projects in mind, the decision was made in 2014 to collect post-burn data on individual plots regardless of what fire affected them - as such, plots in these project units were read after burning in Tipover East Rx and Slopes Rx.

Table 2A: 2024 Flagstaff Area National Monuments Fire Effects Plots Established

Park	Code	Monitoring Unit	Plot Type	Total Plots[1]	Years Data Collected (start-end)	Annual Total (2024)	2024 Collections		
							Install / Pre-burn	Post - Burn	Years 1 - 20
Walnut Canyon NM	PIPO	Ponderosa Pine	FMH – Forest / I&M	13	1993 - 2024	13	13	0	0
Walnut Canyon NM	PIED	Pinyon-Juniper Woodland	FMH – Forest	2	1997 – 2000	All Plots Discontinued[2]			
Sunset Crater NM	BOGR	Montane Meadow	FMH - Grass	10	2002 - 2003	All Plots Discontinued[3]			
Sunset Crater NM	PIPO	Pine Encroachment of Montane Meadow	FMH - Brush	5	2002 - 2003	All Plots Discontinued[3]			
Wupatki NM	BOER	Plains/Great Basin Grassland	FMH - Grass	4	2002 - 2003	All Plots Discontinued[4]			
Wupatki NM	HIJA	Plains/Great Basin Grassland	FMH - Grass	12	2002 - 2003	All Plots Discontinued[4]			
Total				**46**		**13**	**13**		

[1] Total Plots includes all permanent plots (FMH or I&M) installed to date within a monitoring unit/type.
[2] Walnut Canyon NM FFI database containing the PIED plot data, including plot coordinates, is archived on the NPS IRMA portal (Reference Code: 2222935).
[3] Sunset Crater NM FFI database containing the plot data, including plot coordinates, is archived on the NPS Integrated Resource Management Applications (IRMA) portal (Reference Code: 2221713).
[4] Wupatki NM FFI database containing all plot data, including plot coordinates, is archived on the NPS IRMA portal (Reference Code: 2222001).

During 2015, fire effects monitoring plots within the three Flagstaff Area National Monuments were evaluated to determine their utility in providing feedback for fire management activities in the monuments. As a result of the evaluation, five monitoring types containing 33 total plots were discontinued and archived. The details of the evaluation and decision process are contained in the report "Fire Effects Monitoring for the Flagstaff Area National Monuments: Overview, Status, and Future Direction" (Bunn 2015; National Park Service Integrated Resource Management Applications Data Store Reference Code: 2223756). GRCA has worked with the I&M program since 2015 to share data and repeat the pre-burn fuel, pole-sized tree, and overstory tree measurements in eleven FMH-established ponderosa pine (PIPO) plots and two I&M-established PIPO plots in Walnut Canyon National Monument. A copy of the FFI database containing the existing plot data is available on the NPS IRMA portal (Reference Code: 2194013).

E. Monitoring Results & Recommendations

Introduction

Grand Canyon National Park's Fire Ecology Program has installed 148 permanent FMH-style plots to date. As of 2024, 125 (previous number updated and corrected) of the 148 plots have burned. This large body of data allows us to report results to our desired level of statistical accuracy for many of our major management objectives.

Specific management objectives have been created for three monitoring / plots types within the Park boundary. Objectives for PIPO (Ponderosa Pine South Rim), PIPN (Ponderosa Pine North Rim), and PIAB (Ponderosa Pine with White Fir Encroachment / Mixed Conifer) were identified within the 2012 monitoring plan and are regularly assessed as new data become available.

Two additional monitoring types, PIEN (Spruce-Fir) and PIED (Pinyon-Juniper) are not included in regular assessments as: (1) these areas were previously thought to be within the natural fire regime, (2) prescribed fires are not the management focus in these areas, and (3) quantitative objectives have not been updated or established. Giving shifting fire conditions, this now represents a large data gap on the GRCA landscape that the program will seek to address, but for these reasons analysis of data from these plots is not presented here.

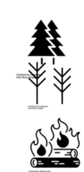
Within the 2024 field season new FMH data were collected for PIPO, PIAB, PIEN, and PIPN, as indicated in **Table 2**. Data from 2024 were quality controlled using long-standing methods in FFI, Microsoft Excel, and new QA/QC queries in the R and R Studio suite (R Core Team 2023). Data for analysis were generated using long-standing methods via FFI queries and Microsoft Excel. Query and Excel results were then analyzed statistically and graphically in the R and R Studio suite – these results are reported below in the *R Analysis* section. Results were also analyzed using long-standing methods via the FFI and Microsoft Excel – these are presented as traditionally done below in the *Traditional Analysis* section.

In the future, obtaining the table and join structure internal to the FFI database will enable much more efficient QA/QC and analysis procedures and workflows. Doing so will not only leverage more effective, efficient, and repeatable processes in R, but also expand the types of analyses that can be conducted and questions that can be answered using currently un-tapped FMH plot data. This will be a necessary step to provide for future revisions of the monitoring plan, and updated objectives that address shifting baselines, appropriate concerns for shifting climate and prescribed burn envelopes – and to do so without duplicating the enormous effort that has already gone into designing FFI's crucial data structure and capabilities (which are still foundational and crucial to the process as well).

R Analysis

Introduction & Methods

Each restoration objective is presented below for each plot type. Restoration objectives of similar nature are represented with the same icons across plot types (trees for retention of large canopy trees; twigs for retention of small pole trees; and a fire log for fuel loadings). All icons are sourced from the nounproject.com and contain the required citation info on them.



Objectives successfully achieved are represented by green check marks (√). Objectives not yet successfully achieved are represented by red x marks (×), and objectives with somewhat mixed results are represented by both a green check mark and a red x mark (√×), or with a green check mark and red question mark if results after multiple fire entries seem questionable (√**?**). Results are also depicted graphically and in a textual narrative, with summary and test statistics, as appropriate.

The boxplots that appear below for each restoration objective show the upper and lower quartiles (whiskers), middle quartiles (box), median (middle line), and mean (star) for each measurement type. The occurrence of fires between measurement types is represented in all graphs using vertical, dotted red lines. The minimum, maximum, or range of objectives are represented in each graph using horizontal, dotted blue lines.

For each objective, data were analyzed in the R and R Studio suite (R Core Team 2023) using a linear mixed effects model that acknowledges the repeated measures made on the same plots (approximates a repeated measures ANOVA, but with additional capabilities). This is the first statistical test result presented under each objective to identify if there is any overall statistical difference between measurement types. Then, post-hoc analyses were conducted for each objective using the emmeans package (Lenth 2025) in R as a post-hoc analysis, to provide 95% confidence intervals for the mean of each measurement type and statistically test contrasts between specific measurement type pairs, as appropriate. This method utilizes the Tukey method for adjusting statistical significance for multiple comparisons. The 95% confidence intervals are reported in tables for measurement types with enough data. In some cases the median is also reported due to limited data and/or relatively wide or uncertain 95% confidence intervals. The minimum number of data points required for reporting statistics was adjusted based on the 95% intervals, spread of data points, and a variety of graphical and statistical indications such as the skewness of the data.

At the end of each narrative summary of the results appear important notes specific to the data for that objective. However, one important note applies across objectives: *Data that does not appear in this graph/analysis may be due to the way the original objective was worded and subsequent queries constructed, rather than due to a lack of data. For example, queries for some objectives were constructed around two years post-fire, so queries may not have been constructed to pull data from five or 10 years after a fire unless they also represent pre-fire data for subsequent fires. As a result, some of data may not have been captured in the traditionally used queries and may not appear in the following graphs and analyses.* Working with FFI developers and managers to better understand FFI internal table structure and the ability to translate it easily to R will be crucial to resolving these gaps for future analyses and objective setting.

South Rim Ponderosa Pine (PIPO) Objectives

√√

PIPO: Maintain >14 large ponderosa pines (≥16" DBH) / acre (5 years post-fire).

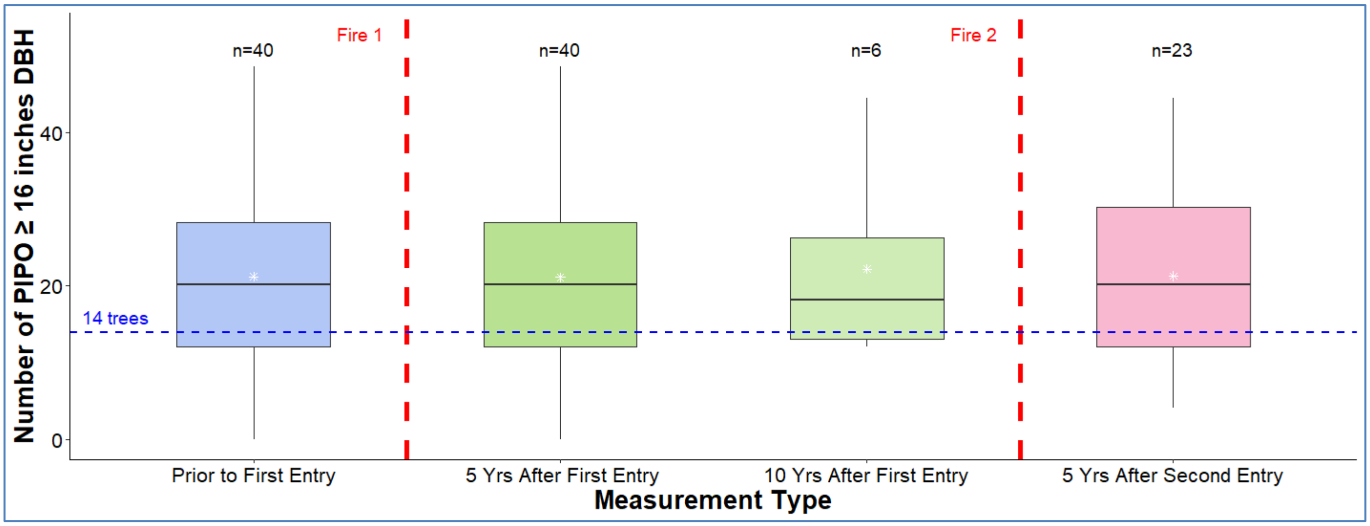


Figure 4: GRCA has successfully retained large ponderosa pine trees at a density exceeding 14 trees per acre within South Rim PIPO plots following first and second entry fires.

There is no statistical difference between the number of ponderosa pines ≥ 16 inches DBH under different measurement types or periods (F=0.24; p=0.87; **Figure 4**). Using the post-hoc analysis, we can see that the 95% confidence interval for the mean of each group is approximately 16 to 25 ponderosa pines per acre of this size (≥ 16 inches DBH).

PIPO: Reduce ponderosa pine poles (1-6” DBH) to 16-81 trees/acre (2 years post-fire).

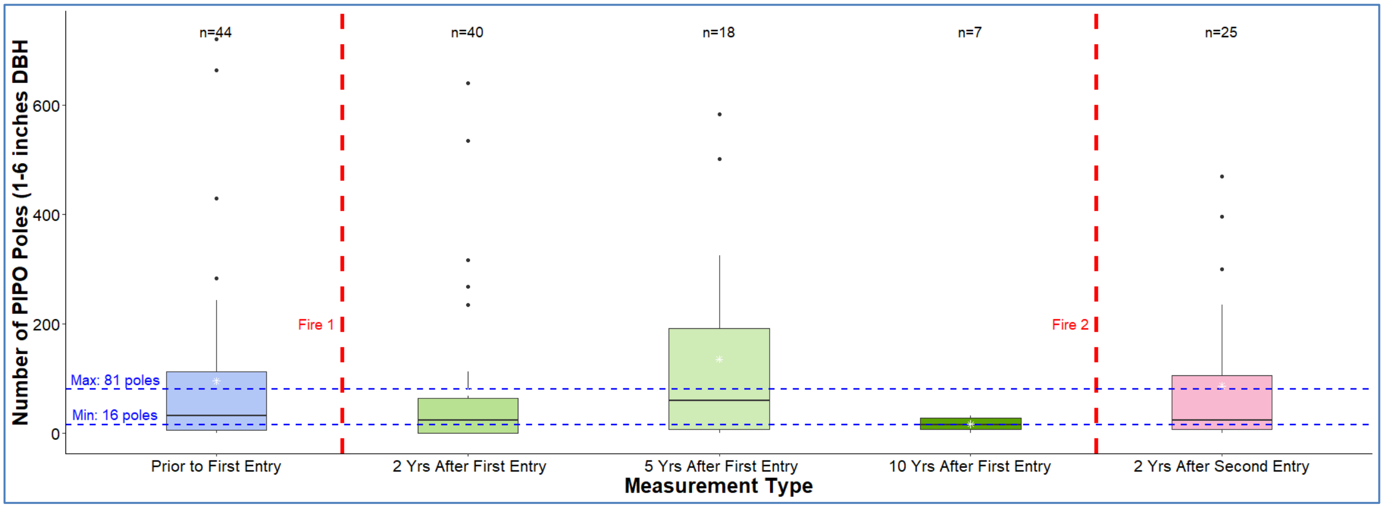


Figure 5: Median ponderosa pole numbers per acre on the South Rim are typically within the desired range. However, the 95% confidence intervals exceed the desired range in each measurement group. Additionally, mean values exceed the desired range two years after the second entry fire, reflecting skewness in the data caused by plots with high pole numbers. Plots with high pole numbers should be investigated, located and targeted for appropriate follow-up actions on the ground. Statistical evaluations should be refined to investigate and better account for the skewness in the data.

There is a statistical difference between the number of ponderosa poles (1-6 inches DBH) under different measurement types or periods ($F=7.47$; $p=0.00003$; **Figure 5**). Using the post-hoc analysis, we can see the 95% confidence intervals for the mean of each measurement type below in **Table 3**. While the median pole numbers per acre are within the desired range for each measurement type, the means sometimes exceed the desired range, and the 95% confidence intervals exceed the desired range for each measurement type, as can be seen in **Table 3**.

Table 3: 95% confidence intervals for ponderosa poles numbers/acre in each measurement type**.**

95% CI / Measurement Type	Prior to First Entry Fire	2 Years After First Entry	5 Years After First Entry	10 Years After First Entry	2 Years After Second Entry
Minimum	58	31	28	11	10
Maximum	147	121	121	115	101

Notes: 1) Due to the skewness caused by outliers, there may be a better statistical test to apply. We will continue to refine the paired repeated measures analyses, including to address this challenge and understand the location and meaning of the large number of outliers in this dataset.

PIPO: Reduce total fuel load to 0.2-9.3 tons/acre (immediately following a fire).

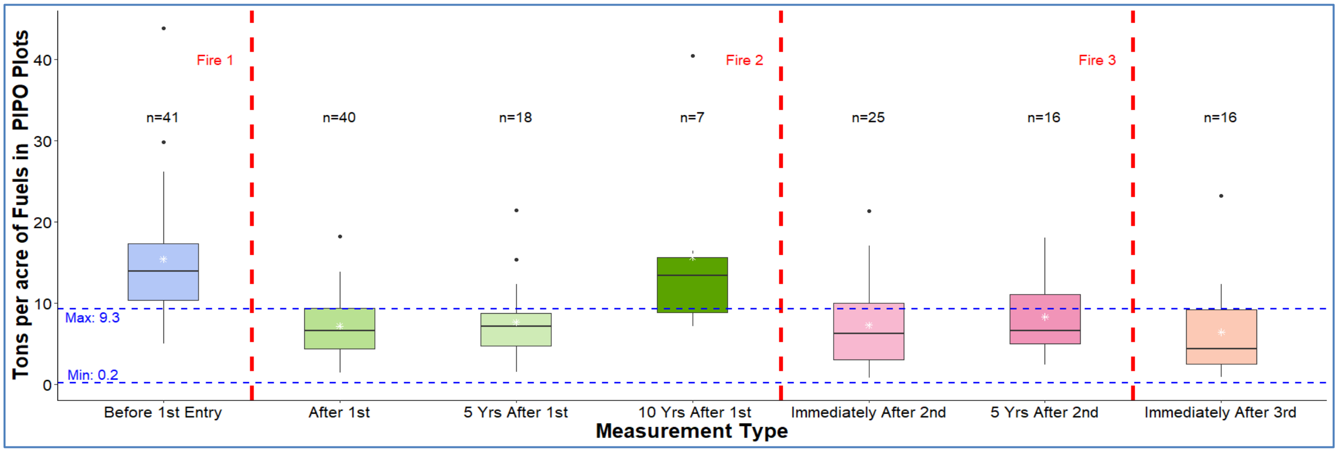


Figure 6: Fuel loadings within PIPO plots on the South Rim are typically within the desired range immediately post-fire entry and up to 5 years after a fire entry. After approximately 10 years after a first entry fire, fuel loadings are back up to levels similar to those seen prior to first entry fire. However, subsequent fire entries successfully return loadings to the desired range.

There is a statistical difference between the number of ponderosa poles (1-6 inches DBH) under different measurement types or periods (F=18.03 ; p<0.00000; **Figure 6**). Using the post-hoc analysis, we can see the 95% confidence intervals for the mean of each measurement type below in **Table 4**. We can see that after fire entries 1, 2, and 3, fuel loadings in these plots are within the desired range, and that 10 years after the first entry fire fuel loadings approximate those prior to the first entry fire, but that subsequent entries have the desired effect. Post-hoc pairwise contrasts (with Tukey adjustments for multiple comparisons) between treatment groups demonstrate that these results are significant. For example, the pre and post first entry values are significantly different (t=8.23, p<0.0001 for immediate and t=6.052, p<0.0001 for 5 years after), while the fuel loadings prior to first entry and those found 10 years after the first entry fire are not statistically different (t=0.26, p=1.0).

Table 4: 95% confidence intervals for fuel loadings (tons/acre) in each measurement type**.**

95% CI / Measurement Type	Prior to First Entry Fire	After 1st Entry	5 Years After 1st Entry	10 Years After 1st Entry	After 2nd Entry	5 Years After 2nd Entry	After 3rd Entry
Minimum	13.6	5.6	5.0	11.0	4.8	5.1	3.23
Maximum	17.2	9.2	10.0	18.7	9.1	10.4	8.46

North Rim Ponderosa Pine (PIPN) Objectives

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PIPN: Maintain > 17 large (≥ 16' DBH) conifers per acre (five years post-fire).

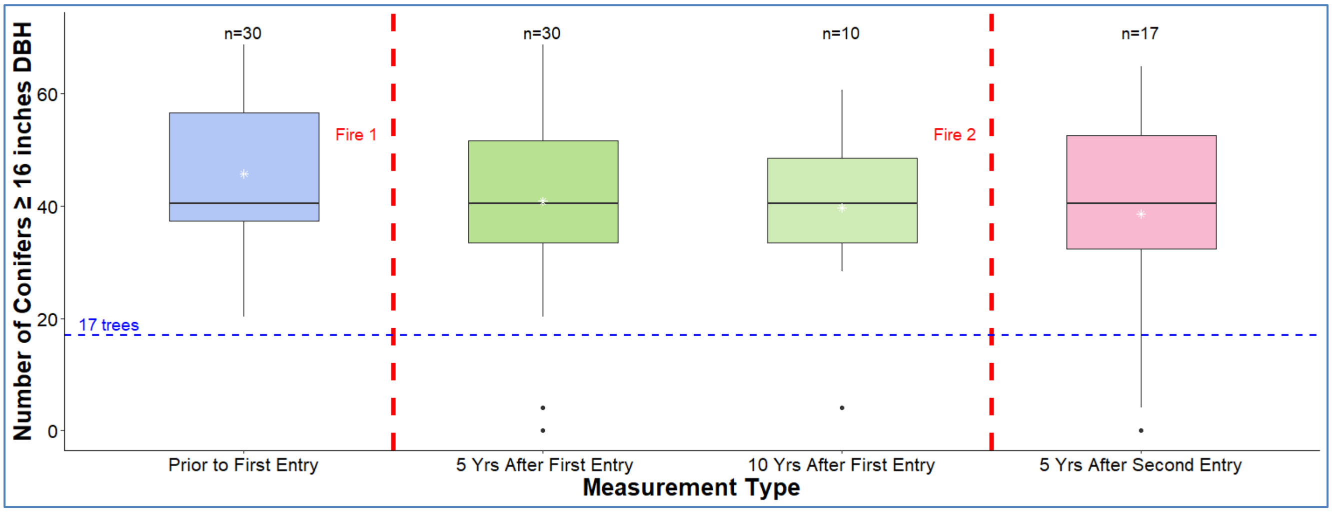

Figure 7: Large conifer trees (with a DBH greater than or equal to 16 inches) have successfully been retained at a density >17 trees per acre within PIPN plots on the North Rim following first and second entry fires.

Overall, measurement type does make a difference in the number of conifers per acre (F=3.19, p=0.031; **Figure 7**). However, the 95% confidence intervals for the number of conifers per acre in these plots are above 17 for all measurement types, typically ranging from 33-40 on the lower end to 46-51 on the higher end. We can see from **Figure 7**, however**,** that after both the first and second entry fires there are some plots with outlying low numbers of conifers per acre. It would be helpful to understand why that is the case and incorporate lessons learned into future practice, future efforts should investigate the cause of these outliers.

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PIPN: Reduce pole-sized (1-6” DBH) conifers to 16-81 trees/acre (2 years post-fire).

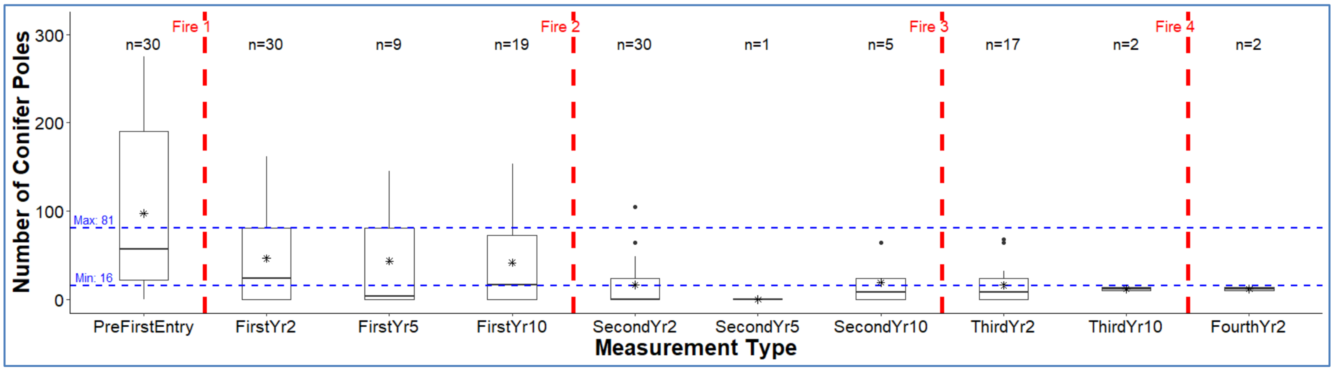

Figure 8: PIPN plot median conifer pole numbers per acre on the North Rim are typically within the desired range following first entry fires. However, medians, means, and the 95% confidence intervals for conifer poles 2 years after the second and third entry fires trend toward the lower end of the desired range – something to keep an eye on.

There is a statistical difference between the number of conifer poles (1-6 inches DBH) under different measurement types or periods (F=4.98 ; p<0.00000; **Figure 8**). The post-hoc analysis reveals that the first entry fire significantly reduced conifer poles (t=3.3; p=0.0425), an effect which generally tends to endure into future measurements. The 95% confidence intervals for the mean of each measurement type appear below in **Table 5**. Medians, means, and the 95% confidence intervals for conifer poles 2 years after the second and third entry fires trend toward the lower end of the desired range – something to keep an eye on.

Table 5: 95% confidence intervals for conifer poles per acre in each measurement type**.**

95% CI / Measurement Type	**Prior to 1st Entry Fire**	**2 Years After 1st Entry**	**5 Years After 1st Entry**	**10 Years After 1st Entry**	**2 Years After 2nd Entry**	**2 Years After 3rd Entry**
Minimum	90	24	12	2	-30	-30
Maximum	182	116	143	106	63	76

Notes: 1) Due to limited data for some measurement types, statistical comparisons reported are limited to where there are at least 17 measurements.

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PIPN: Reduce total fuel load to 0.2-15.7 tons/acre (immediately following a fire).

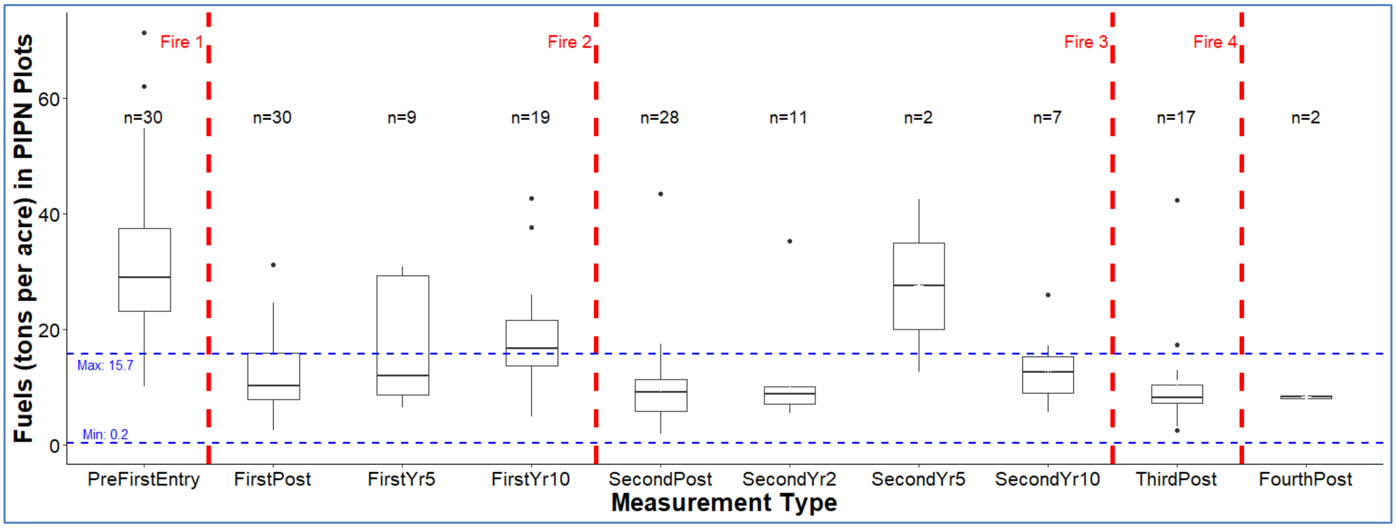

Figure 9: PIPN plot fuel loadings on the North Rim were well out of the desired range prior to first entry fires, and are now typically within the desired range immediately post-fire entry and up to 5-10 years after a fire entry.

There is a statistical difference between fuel loadings under different measurement types or (F=15.57 ; p<0.00000; **Figure 9**). Using the post-hoc analysis, we can see that the first entry fire significantly and immediately reduced the fuel loadings (t=9.062; p<0.0001). This effect largely endures for ten years (t=5.41; p<0.0001) such that there is no statistical difference between fuel loadings immediately after the first entry fire and ten years after the first entry fire (t=-2.37; p-0.3588). Visually, we can see in **Figure 9** that the overall range of fuel loadings on PIPN plots do start to creep upward five or ten years after a fire, but this trend is not great enough to be significant, and subsequent fire entries appear be addressing any potential increase (**Table 6**).

Table 6: 95% confidence intervals for fuel loadings (tons/acre) in each measurement type.

95% CI / Measurement Type	Prior to First Entry Fire	After 1st Entry	10 Years After 1st Entry	After 2nd Entry	After 3rd Entry	After 4th Entry
Minimum	27.7	8.4	13.5	6.1	6.1	2.3
Maximum	35.0	15.8	22.3	13.7	15.4	27.1

Notes: 1) Due to limited data for some measurement types, statistical comparisons reported are limited to where there are at least 17 measurements.

North Rim Ponderosa Pine with White Fire Encroachment (PIAB) Objectives

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PIAB: Maintain >20 large conifers (≥16” DBH) per acre (five years post-fire).

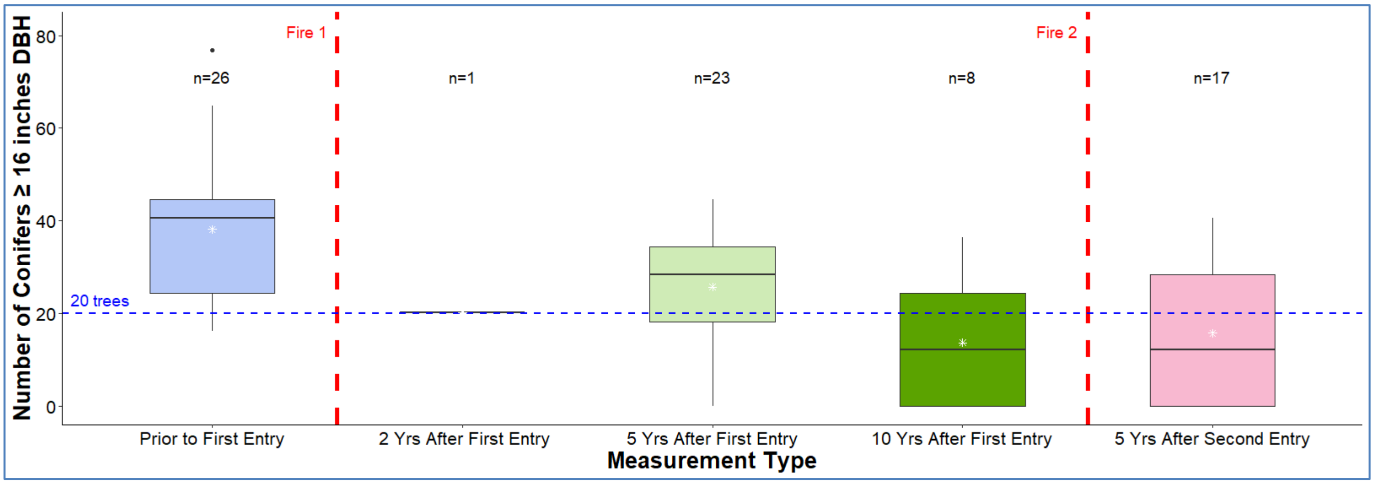

Figure 10: Large conifer density in PIAB plots was significantly decreased following first entry fire, placing median and mean densities, and most of the 95% confidence intervals for the mean densities, below the desired threshold of 20 trees/acre by 10 years after the first entry fire and five years after the second fire where that data is available.

Measurement type makes a significant difference in PIAB number of conifers per acre (F=9.48, p<0.0000; **Figure 10**). First entry fire significantly decreased the number of large conifers five and ten years later (t=3.45, p=0.0099; t=4.33, p=0.0006 respectively). The 95% confidence interval for the mean was still above the desired minimum threshold five years after the first entry fire. However, 10 years after the first entry fire the median and mean densities of large conifers falls below the desired threshold, and even the upper limits of the 95% confidence intervals for the mean are barely above that threshold – this does not change five years after the second fire (**Table 7**). This trend needs further investigation for appropriate actions. Some plots were affected by repeated high severity fires (Outlet / Fuller). During 2024 we proposed and were successfully awarded funding to address effects from these fires. The project has been on hold due to funding pauses, but will resume if permitted by the new timeline and review process.

Table 7: 95% confidence intervals for conifer poles per acre in each measurement type**.**

95% CI / Measurement Type	Prior to 1st Entry Fire	5 Years After 1st Entry	10 Years After 1st Entry	5 Years After 2nd Entry
Minimum	32.54	19.48	4.62	9.30
Maximum	43.8	31.4	24.5	23.1

Notes: 1) Due to limited data for some measurement types, statistical comparisons reported are limited to where there are at least 5 measurements.

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PIAB: Reduce pole-sized (1-6” DBH) conifers to 16-100 trees/acre (2 years post-fire).

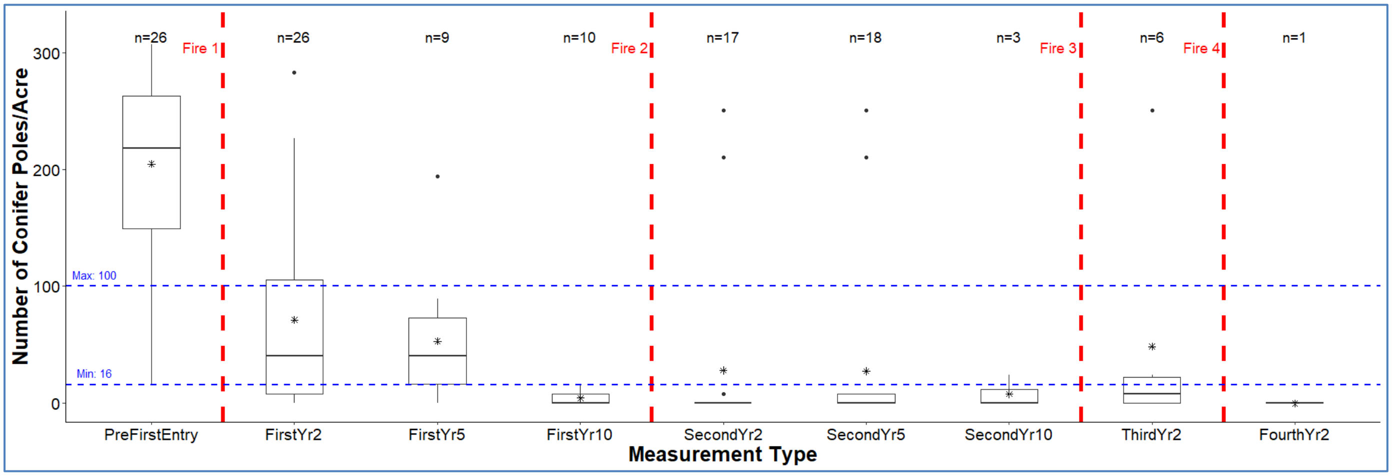

Figure 11: PIAB plot conifer pole densities were significantly reduced to within the desired range two years after first entry fire. However, pole densities largely fall below the desired range approximately 10 years after the first fire, a trend that continues after subsequent fires, while some select plots have extremely high densities.

Measurement type makes a significant difference in the number of PIAB conifer poles (1-6 inches DBH; F=15.62 ; p<0.00000; **Figure 11**). Post-hoc analyses demonstrate that the first entry fire significantly reduced conifer poles two years after the fire (t=8.013; p<0.0001), with a median and 95% confidence interval that seem to reflect the desired range for conifer pole density in these plots (**Table 8**), with some skewing by outlier plots that have very high density. However, medians, means, and the 95% confidence intervals for conifer poles 10 years after the first entry fire, and after subsequent fires are noticeably at the lower end of the desired range, while select outlier plots have very high pole densities. This trend needs further investigation for appropriate actions to be taken. Some plots were affected by high severity fires (Outlet / Fuller). During 2024 we proposed and were successfully awarded funding to strategically address effects from these fires. The project was on hold due to funding pauses, but will resume if permitted by the new timeline and review process.

Table 8: 95% confidence intervals for conifer poles per acre in each measurement type**.**

95% CI / Measurement Type	Prior to 1st Entry Fire	2 Years After 1st Entry	10 Years After 1st Entry	2 Years After 2nd Entry	5 Years After 2nd Entry
Minimum	246	30	-24	-24	-25
Median	259	40.5	10	17	18
Maximum	329	113	107	78	75

Notes: 1) Due to limited data for some measurement types, statistical comparisons reported are limited to where there are at least 10 measurements.

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PIAB: Reduce total fuel load to 1.7-19.0 tons/acre (immediately following a fire).

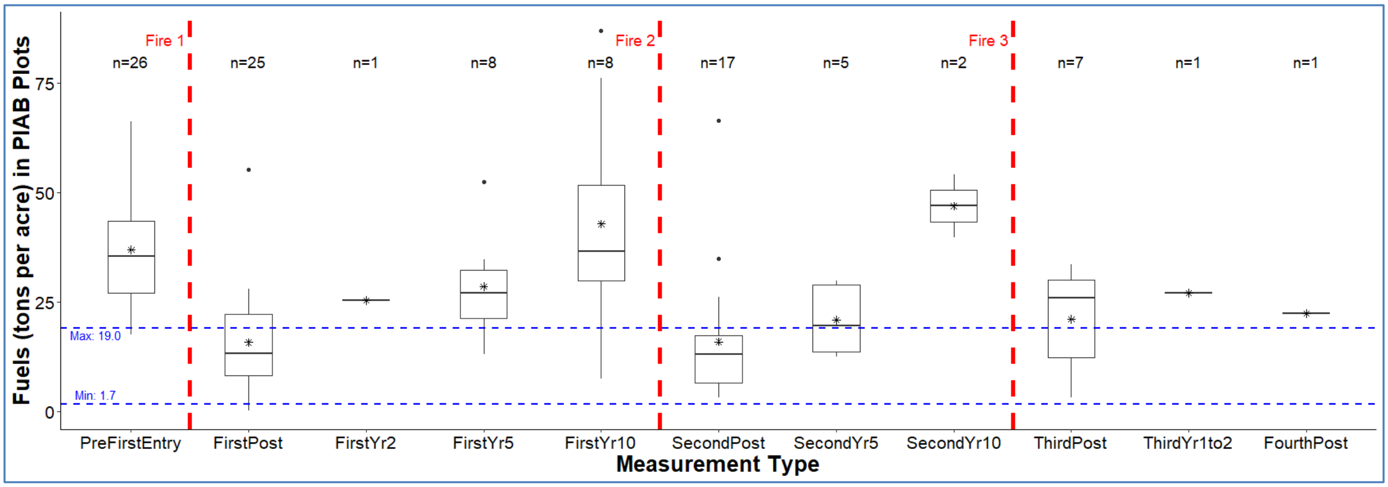

Figure 12: PIAB plot fuel loadings on the North Rim were well out of the desired range prior to first entry fires, and were significantly reduced by first entry fire, placing the mean, median, and most of the 95% confidence interval of mean within the desired range. Similar effects were seen for second entry fire.

Fuel loadings under different measurement types are significantly different (F=6.86 ; p<0.00000; **Figure 12**). Using post-hoc analyses, we can see that the first entry fire significantly and immediately reduced the fuel loadings (t=9.062; p<0.0001). This effect is reversed by ten years after the first entry fire (t=-5.3; p<0.0001). The second entry fire has a similar effect, significantly reducing fuel loads from their levels from before the first entry fire and from 10 years after the first entry fire (t=5.26, p-0.0001;t=5.078, p=0.0001 respectively). Third entry fires do not appear as effective (t=2.951, p=0.126; t=2.93, p=0.384 respectively), but this is likely due at least in part to a relatively small number of plots showing data for 10 years after the second fire entry, and that have experienced third entry fires at this time.

Table 9: 95% confidence intervals for fuel loadings (tons/acre) in each measurement type**.**

95% CI / Measurement Type	**Prior to First Entry Fire**	**After 1st Entry**	**5 Years After 1st Entry**	**10 Years After 1st Entry**	**After 2nd Entry**	**5 Years After 2nd Entry**	**After 3rd Entry**
Minimum	31.6	10.4	17.58	34.47	9.32	8.58	10.28
Maximum	42.4	21.5	36.8	53.7	22.7	32.7	30.8

Notes: 1) Due to limited data for some measurement types, statistical comparisons reported are limited to where there are at least 5 measurements.

Top: Fire Effects crew and North Rim Interpretation staff read a plot together on Swamp Ridge
Bottom left: Antelope horns (*Asclepias asperula*)
Bottom right: Woodland pinedrops (*Pterospora andromedea*)
(photos by Li Brannfors)

Traditional Analysis

Restoration Objectives

Restoration objectives are centered around first and second entry fires and help to refine desired conditions for each monitoring type (PIPO, PIPN, and PIAB) being managed at GRCA. Objectives for first and second entry fires are listed in **Table 10** and briefly outline management objectives for fuel loading and tree density. Data were analyzed and presented in **Table 10**. Newly created results are highlighted with a red outline.

Fuel Loading Restoration Results

When examining the results of our FMH analysis, Grand Canyon Fire Management has achieved its first entry, total fuel loading objectives (desired range in parentheses) in the PIPO (0.2 – 9.3 tons/acre), PIPN (0.2 – 15.7 tons/acre), and PIAB (1.7 – 19 tons/acre) monitoring types.

After second entry fires, fuel loading values were also within the targeted range for PIPO, PIPN, and PIAB; however, there may be more fuel loading than desired for PIAB as confidence limits include values outside the objective range.

Pole and Overstory Tree Density Restoration Results

In the PIPO and PIPN monitoring types, it is important to note that GRCA has not installed the number of plots needed to gain statistical confidence to overcome the variability in pole-sized tree (1-6" DBH) density. Within the PIAB monitoring type, current sample sizes for pole-sized trees do indicate that statistical confidence can be achieved for post-burn values.

In the PIPO monitoring type, pole-sized tree density objectives (16-81 trees/acre) are likely being met after first entry, and they are probably not being met after second entry. Confidence limits outside the objective range for first entry fire indicate there may be more poles than desired; contrary to this, for second entry the mean density is outside the desired range, but the lower confidence limit is within the targeted range.

When evaluating data for the PIPN monitoring type, pole-sized tree density objectives (16-81 trees/acre) are likely being met for both first and second entry fire. However, there may still be too many poles after first entry with confidence limits extending above the targeted range, and conversely too few poles after second entry with limits below the range. These results indicate the extreme variability in pole-sized trees within North Rim Ponderosa Pine.

After first entry fires in the PIAB monitoring type, pole-sized tree density (16-100 trees/acre) objectives are being met. After second entry fires in PIAB, pole-sized tree density also fell within the objective range, but the confidence limits extended below the target, indicating the possibility of more mortality in this size class than desired.

For large tree (>16" DBH) density, minimum plot numbers have been reached for all three analyzed monitoring types and can provide reliable analysis. Mean large tree density objectives are being met in PIPO (>14 trees/acre), PIPN (>17 trees/acre), and PIAB (>20 trees/acre) for all first entry burns. When looking at second entry fire, values five years post-burn were within the targeted range for PIPO and PIPN. PIAB mean density fell outside the desired range but the lower confidence limit is now within the targeted range, moving toward the objective of retaining sufficient large trees.

Table 10: Restoration Management Objectives

Monitoring Unit	Restoration Management Objectives	Monitoring Results (n = # of plots)		Objectives Achieved? (Data Years)		Minimum Plot #s Achieved?
		1st Entry	2nd Entry	1st Entry	2nd Entry	
Ponderosa Pine (PIPO) South Rim	Reduce fuel load to 0.2-9.3 tons/acre immediate post-burn	7.2 ± 0.8 tons/acre (-48%) (n=40)	7.3 ± 1.4 tons/acre (-52% due to fire 1 & 2) (-13% due to fire 2 only) (n=25)	YES (1992 – 2023)	YES (1998 – 2022)	YES n=10
	Reduce PIPO poles (1-6” DBH) to 16-81 trees/acre 2 years post-burn	75.9 ± 29 trees/acre (-24%) (n=40)	86.8 ± 35 trees/acre (-37% due to fire 1 & 2) (-11% due to fire 2 only) (n=25)	YES* (1994 – 2021)	NO* (2000 – 2023)	NO n=61
	Maintain large PIPO (≥16” DBH) of >14 trees/acre density 5 years post-burn	21.1 ± 2.5 trees/acre (0%) (n=40)	20.4 ± 3.2 trees/acre (2% due to fire 1 & 2) (1% due to fire 2 only) (n=24)	YES (1997 – 2024)	YES (2003 – 2024)	YES n=14
Ponderosa Pine (PIPN) North Rim	Reduce fuel load to 0.2-15.7 tons/acre immediate post-burn	12.1 ± 1.6 tons/acre (-56%) (n=30)	9.9 ± 1.9 tons/acre (-63% due to fire 1 & 2) (-40% due to fire 2 only) (n=28)	YES (1992 – 2011)	YES (2005 – 2018)	YES n=11
	Reduce density of conifer poles (DBH of 1-6”) to 16-81 trees/acre 2 years post-burn	70.2 ± 33.4 trees/acre (-58%) (n=30)	17.9 ± 6.5 trees/acre (-80% due to fire 1 & 2) (-23% due to fire 2 only) (n=28)	YES* (1994 – 2013)	YES* (2007 – 2020)	NO n=48
	Maintain large conifer (≥16” DBH) density of >17 trees/acre 5 years post-burn	40.9 ± 3.8 trees/acre (-10%) (n=30)	38.6 ± 6.6 trees/acre (-17% due to fire 1 & 2) (-4% due to fire 2 only) (n=17)	YES (1997 – 2016)	YES (2010 – 2023)	YES n=4
Ponderosa Pine w/ White Fir Encroach-ment (PIAB) North Rim	Reduce total fuel load to 1.7-19.0 tons/acre immediate post-burn	15.9 ± 2.9 tons/acre (-55%) (n=25)	16.0 ± 5.0 tons/acre (-58% due to fire 1 & 2) (-43% due to fire 2 only) (n=17)	YES (1993 – 2017)	YES* (2000 – 2019)	YES n=5
	Reduce conifer poles (1-6” DBH) to 16-100 trees/acre 2 years post-burn	71.3 ± 20.5 trees/acre (-70%) (n=26)	28.0 ± 24.8 trees/acre (-87% due to fire 1 & 2) (-45% due to fire 2 only) (n=17)	YES (1995 – 2019)	YES* (2002 – 2021)	YES n=9
	Maintain large conifer (≥16” DBH) density of >20 trees/acre 5 years post-burn	24.6 ± 3.6 trees/acre (-30%) (n=25)	15.7 ± 4.8 trees/acre (-46% due to fire 1 & 2) (-10% due to fire 2 only) (n=17)	YES (1998 – 2022)	NO* (2005 – 2024)	YES n=7

NOTE: Overall results above that appear in grey cells have been updated as a result of 2024 data collection. Assessment of objective success and fulfillment of minimum plot requirements are based on 80 percent confidence intervals. Minimum plot calculations are based on pre-fire values, with R-value of 20 for overstory tree and fuel assessment and R-value of 25 for pole-sized tree assessment; variable fire conditions increase the minimum number of recommended plots for post-fire analysis.
YES* indicates that the mean value meets stated objectives, but the confidence interval is outside the range of objective values.
NO* indicates that the mean value does not meet stated objectives, but the confidence interval is inside the range of objective values.

Maintenance Management Objectives Overview

Maintenance objectives for third and fourth entry fire help GRCA to refine the desired conditions of the landscape within each monitoring type and are described briefly in **Table 10A**. On the South Rim, maintenance burning will likely continue in the form of prescribed fires, while on the North Rim, the expectation is that wildfires will be utilized to achieve maintenance objectives. In the absence of wildfires utilized for resource objectives, prescribed fire will also be a tool to achieve management objectives on the North Rim.

Fuel Loading Maintenance Results

Grand Canyon Fire Management has achieved third and fourth entry total fuel loading objectives in the PIPO (0.2 – 9.3 tons/acre) and PIPN (0.2 – 15.7 tons/acre) monitoring types.

Results for PIAB unfortunately fall above the desired range. However, within this monitoring type, confidence limits do include acceptable values.

Tree Density Maintenance Results

Within in all three monitoring types (PIPO, PIPN, and PIAB), GRCA has not burned the number of plots needed to overcome the extreme variability in tree density to produce reliable statistics.

Preliminary results utilizing our current sample size show that in the PIPO monitoring type, objectives (43-135 trees/acre) are not likely being met for trees >1” DBH. Mean density is outside the desired range, but the lower confidence limit is within the targeted range.

Maintenance objectives for pole sized trees (1-6” DBH) are being met when evaluating data for the PIPN monitoring type (<81 trees/acre), acknowledging that the sample size is still insufficient.

PIAB pole sized tree density objectives (<100 trees/acre) are on track. However, when viewing the confidence intervals, lower limits extend well below the targeted threshold and values outside the interval are rejected as plausible. These values reflect our inadequate sample size and reinforce the need to increase our number of plots burned, as well as evaluate our minimum plot numbers needed for reliable statistics for pole sized trees.

When considering maintenance objectives for poles in all three active monitoring types there is extreme variability in the number of pole sized trees, both pre- and post-fire. Our current methodology includes all qualifying plot reads and outliers are not being excluded. Currently calculations represent the full range of natural landscape variability within these monitoring types. It should also be noted that in all instances where the sample size is small and the minimum number of plots has not been reached, each additional plot reading in that monitoring type has the potential to greatly influence the result. Any interpretation of results should take this lack of statistical confidence in existing values into account.

Conclusion

Of the six maintenance objectives listed in **Table 10A**, we can say with reasonable confidence that we are achieving four objectives after third and fourth entry fire. Where confidence limits extend outside of the desired range or minimum sample sizes are not close to being reached, we are less certain about two of our management objectives.

Table 10A: Maintenance Management Objectives

Monitoring Unit	Maintenance Management Objectives	Monitoring Results 3rd/4th Entry (n = # of plots)	Objectives Achieved? (Data Years)	Minimum Plot #s Achieved?
Ponderosa Pine (PIPO) South Rim	Maintain fuel load of 0.2-9.3 tons/acre immediate post-burn	6.4 ± 1.9 tons/acre (-59 percent due to fire 1, 2, & 3) (-25% due to fire 3 only) (n=16)	YES (2005 – 2011)	YES n=10
	Maintain density of PIPO ≥1” of 43-135 trees/acre 5 years post-burn	151.3 ± 34.5 trees/acre (-21% due to fire 1, 2, & 3) (-8% due to fire 3 only) (n=16)	NO* (2010 – 2016)	NO n=43
Ponderosa Pine (PIPN) North Rim	Maintain total fuel load of 0.2-15.7 tons/acre immediate post-burn	10.8 ± 2.8 tons/acre (-55% due to fire 1, 2, & 3 or 4)[1] (-18% due to most recent entry) (n=17)	YES (2007 – 2022)	YES n=11
	Maintain conifer pole (1-6” DBH) density of <81 trees/acre 2 years post-burn	15.2 ± 6.4 trees/acre (-81% due to fire 1, 2, & 3 or 4)[1] (-6% due to most recent entry) (n=17)	YES (2009 – 2024)	NO n=48
Ponderosa Pine w/ White Fir Encroachment (PIAB) North Rim	Maintain fuel load of 1.7-19.0 tons/acre immediate post-burn	19.5 ± 5.8 tons/acre (-50% due to fire 1, 2, & 3 or 4)[1] (-14% due to most recent entry) (n=7)	NO* (2017 – 2019)	YES n=5
	Maintain conifer pole (1-6” DBH) density of <100 trees/acre 2 years post-burn	41.6 ± 50.5 trees/acre (-48% due to fire 1, 2, & 3 or 4)[1] (+16% due to most recent entry) (n=7)	YES* (2019-2021)	NO n=9

NOTE: Overall results that appear in grey boxes above have been updated as a result of 2024 data collection. Assessment of objective success and fulfillment of minimum plot requirements are based on 80 percent confidence intervals. Minimum plot calculations are based on pre-fire values, with R-value of 20 for overstory tree and fuel assessment and R-value of 25 for pole-sized tree assessment; variable fire conditions increase the minimum number of recommended plots for post-fire analysis.
YES* indicates that the mean value meets stated objectives, but the confidence interval is outside the range of objective values.
NO* indicates that the mean value does not meet stated objectives, but the confidence interval is inside the range of objective values.
[1] Both 3rd and 4th entry fires are considered maintenance burns, and only the most recent maintenance burn data are analyzed for each plot. In future years, we will likely analyze 3rd and 4th entry results separately, but currently lack the statistical strength to do so.

F. Research, Planning, and Communication

Research & Publications

In addition to the data gaps identified with researchers as detailed in **Section C** and **Table 1**, a variety of research has taken place in and around Grand Canyon National Park recently. **Appendix C** lists publications which could have local fire management implications, but did not directly involve staff or data from GRCA Fire. The following are previously unlisted publications since 2020 involving research related to fire based on data gathered in Grand Canyon National Park, involving information extracted from and/or with support and help from the GRCA Fire program:

- McClure EJ, Coop JD, Guiterman CH, Margolis EQ, Parks SA. Contemporary fires are less frequent but more severe in dry conifer forests of the southwestern United States. Communications Earth & Environment. 2024 Oct 11;5(1):581.
- Mouallem N. *Reburns of High Severity Patches: Effects on Ponderosa Pine Regeneration and Plant Community Composition*. (Master's thesis, Utah State University). 2024
- Mueller S, Sample M, Evans A, Flatley W, Thode A, Friggens M. Fire-climate interactions in the Southwest: Literature review and annotated bibliography. Gen. Tech. Rep. RMRS-GTR-432. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station. 234 p. https://doi. org/10.2737/RMRS-GTR-432.. 2024;432.
- Padian MT. *Anthropogenic Fire Legacies of the Colorado Plateau: An Ecological Investigation of Grand Canyon National Park* (Master's thesis, Northern Arizona University). 2023

Planning

In addition to a variety of planning tasks performed by the Fire Ecologist detailed in Table A-2, major preparedness and planning challenges were identified and addressed, as described in **Section C** and **Table 1**. Many of those activities are also foundational to updating the FMP and Fire Monitoring Plan.

In response to the nationwide A-123 Corrective Action Plan, GRCA reformatted its Fire Management Plan (FMP) during 2024, and will be conducting yearly updates as required.

The Grand Canyon National Park Wildland and Prescribed Fire Monitoring Plan was constructed and approved in 2010. The plan outlines the program of work for Fire Ecology as well as management goals / objectives, monitoring design, data analysis, reporting, and staff roles / responsibilities. The plan incorporates adaptative management practices and promotes a science-based program that relies on current and best available information. In 2022, during the Regional Review of the Fire Ecology program, the validity of the monitoring plan was discussed. It was determined that while although there have been changes in staffing and changes within the Ecology program of work at GRCA, the plan was still valid at that time.

During the next few years, the Fire Ecology program will need to update the 2010 Wildland and Prescribed Fire Monitoring Plan to incorporate shifting fire and drought risks and envelopes, modern innovations and technology, and updated analysis tools. To complete this update, time with FFI developers and managers, and time updating analysis tools and analyses will be crucial to setting innovation and future objectives, as described in **Section C** and **Table 1**.

Outreach and Communication

Outreach and communication are principal values of the Fire Ecology program within GRCA. Outreaching to internal / external partners increases collaboration and communicating results aids in fire planning and the adaptative management process.

During 2024 the GRCA Fire Ecologist conducted a variety of collaborative, outreach, education and interpretive activities which are detailed in **Table A-2**.

During 2024 the GRCA Fire Effects Crew Lead and Assistant Lead conducted a variety of outreach:

- Lead provided 2.5 months of in-person Fire Effects program review, hiring, onboarding, and electronic data collection assistance to Colorado Front Range-Northwest Colorado/Rocky Mountain (ROMO) Fire Ecology.
- Assistant Lead initiated "FFI + R Working Group" with Alaska Western Area Fire Ecologist Sarah Stehn to increase FFI and R literacy within NPS Fire Ecology.
- Asst Lead hosted "Using R for QA/QC of FFI Datasets" workshop in December.
- Provided timely FEMO reports to Burn Bosses and Fire Leadership at Grand Canyon and the Kaibab National Forest for the Telephone Hill and Cape Final prescribed burns on the North Zone.

G. Future Direction

Given the events chronicled in **Table 1, Section C and Appendix B,** during 2025 and 2026, the Fire Ecology program will focus on actions needed to update the program, data, analysis, and objectives as required for the future (e.g. those highlighted in the Executive Summary). However, based on the results detailed in Section C, for efficiency and effectiveness, we will focus on actions within programmatic control that can be done with existing staff until or unless updates arrive regarding the requested and needed assistance.

In particular, the program will seek to utilize existing employee abilities with the R &R Studio Suite to increase the efficiency of data analysis, interpretation, and application to wildfire, prescribed fire and other resource protection decisions. This will be more challenging, progress will be slower, and other duties within existing workloads will have to be re-prioritized without additional assistance. However, focus on this task will make the program more effective and efficient into the future. We will also continue to seek the needed FFI guidance from existing FFI staff and contractors, again the process will be slower without the requested additional assistance, due to the wide range of other duties of existing staff. Yet, these efforts are prerequisites for increasing the effectiveness and efficiency of informing the protection of people and resources, and for risk assessments.

As time allows, the program will also seek to undertake a needed review of the data being collected, particularly in light of the data gaps identified and technological advances available, in preparation for updating the monitoring plan and to more swiftly, efficiently and nimbly address baseline conditions as they change and their impacts on fire risk and outcomes.

H. Links & Additional Reading

Link to NPS Data Store and the 2010 Grand Canyon National Park Wildland and Prescribed Fire Monitoring and Research Plan https://irma.nps.gov/DataStore/Reference/Profile/2193323

Link to NPS Data Store and FFI Database Backups DataStore - Collection Profile - Collection ID 7625

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Appendix A. Staffing and Accomplishments

Table A-1: Fire Ecology Staffing 2024

Employee	Position	Appointment Length	# Pay Periods	Training	NWGG Taskbooks[1]
Lisa Handforth, GS-11	Fire Ecologist	PFT (start PPD 3)	24	N9042	
Li Brannfors, GS-07[2]	Lead Monitor	PFT	26	RT130 ROMO detail (5 PPs)	LTAN-t
Alexandra Lalor, GS-06[5]	Asst Lead Monitor	STF	24.5	RT130 S390 READ refresher	FEMO-t FFT1-t ICT5-t FAL3-t
Madison Tumicki, GS-05	Monitor	Temp (early May-late Oct)	12.5	RT130 READ refresher	FEMO READ/REAF-t[3] FFT1-t ICT5-t FAL3-t
Collin Gilmore, GS-05	Monitor	Temp (early May-late Oct)	12.5	RT130 S212 N9042 SAR Technical Rescue	FEMO-t READ/REAF[3] FAL3[4]
Samantha Westfahl, GS-05	Monitor	Temp (early May-late Aug)	8	RT130 S290 N9042	FEMO-t READ/REAF-t[3] ICT5-t FAL2-t

[1] This represents both open (trainee) taskbooks and those completed in the 2024 season.
[2] Time for Li Brannfors includes 5 PPs detailed at Rocky Mountain National Park as Fire Effects Specialist/Lead Monitor.
[3] NWCG taskbooks do not yet exist for the READ & REAF positions.
[4] Taskbook plus required courses completed and submitted for qualification.
[5] Time for Alexandra Lalor excludes 2 PPs furlough, and includes 1 PP on a river trip and 1 PP working on North Zone fuels projects

Measuring spread of the Cape Final Prescribed Fire along the rim of the Grand Canyon in December (photo by Li Brannfors)

Table A-2: Fire Ecologist 2024 Accomplishments/Focus Areas

Focus Area	Percent Time	Accomplishments and Activities

Planning for an Efficient & Effective Fire Program	60	• Provided technical review of prescribed fire burn and fuels treatment plans, and advised on risk assessments, decision tools, and IDT function to serve as decision support.
		• Served as technical expert in IDTs for PEPC and SRM and other projects for GRCA Branch of Fire & Aviation Management, assisted with a variety of fire planning and reporting, directed GIS model building for fire severity.
		• Conducted site visits to ground-truth burn plan assumptions & techniques.
		• Assisted with hiring, HR, and intake and qualifications updates of seasonal fire positions.
		• Facilitated/oversaw fire effects crew work on sentry milkvetch field surveys and application for funding SMV surveys.
		• Designed projects, identified funding sources, wrote proposals for, and where possible implemented projects to reduce risk, and protect and inform fire management, including:
		    o Post-fire rehabilitation needed to maintain GRCA landscapes, viewsheds, visitor experience, listed species, and prescribed fire program;
		    o Updating the decision-making context to set revised goals and strategies for GRCA forest habitats under shifting prescribed fire and drought envelopes;
		    o Transitioning to modern software and statistics for data management & analysis, to leverage plot data for more efficient/powerful data-driven decision making;
		    o Addressing data gaps for prescriptions.
		• Compliance & planning tasks, including:
		    o Revising MTBS Section 7 burn severity analysis based on historical data & USFWS feedback, providing a path forward for continued prescribed burns and severity tracking.
		    o FMP review & drafting drought and fire resiliency section.
		    o Reviewing projects & permit requests for fire-related concerns.
		• Transitioning from the previous fire ecologist, including:
		    o Locating files, file backups & historical drives;
		    o Setting up computer, tablet, fire database & GIS NIFC and GRCA access, new Fx drive (the old one went down), OneDrive etc.;
		    o Working with intern & IT to resolve issues with R Studio & R Markdown & computer setup over the course of several months.

Presentations/ Education	<1	• Society for Ecological Restoration Annual Conference: Co-led session on planning for fire resiliency • USFWS Regional Leaders Training: Presentation on GRCA's fire & fire ecology programs • Recorded episode of Behind the Scenery podcast on GRCA's fire & fire ecology history and programs • Presentation at North Rim Lodge for visitors on fire ecology program • Presentation to joint tribal council meeting on fire and fire ecology programs and intended projects • Presentation to school/volunteer groups (1) • Interviews in response to public & media inquiries (4) • Meeting with interpretive staff, education staff, visual information specialists, tribal liaisons and many others to plan outreach, partnership, and education events and presentation
NPS Meetings/ Task Groups	<1	Attended to extent possible: • Fire and aviation weekly staff and strategy meetings • Bi-monthly SRM program manager meetings • FMO monthly meetings (periodically as needed) • IMR fire planning office hours (periodically as needed) • IMR fire ecology meetings • R + FFI monthly meetings

Focus Area	Percent Time	Accomplishments and Activities
		• Drought Learning Network Additionally facilitated, organized, presented at, attended: • Mentoring calls with individual learning R, upon request & then monthly • Sharing calls with So AZ fire ecologist • Earth to Sky planning calls to plan regional training in 2025/26 • Weekly fire ecology team meetings
Interagency Work	<1	• Planned & co-led (with SRM) interagency meetings & field trips focused on fire & endangered species for sentry milkvetch (SMV) and Mexican spotted owls (MSO). • Co-developed data management & analysis proposal with USGS to harness fire ecology data for more efficient/powerful data-driven decision-making. • Informal & formal meetings with other departments to share information, advise on fire program needs and goals, identify the best avenues to share information with tribal nations, etc. • Obtained ATR designation.
Internal Collaboration	<1	• Shared information with SRM to establish collaborations, share information & improve efficiency of existing staff in a variety of ways. • Shared data, information, and work with the Inventory & Monitoring program for Mixed Conifer & Pinyon-Juniper fuel types at Grand Canyon, to increase efficiency and effectiveness of both programs.
Fire Assignments and Fire Support	<1	• Provided guidance and support to facilitate crew, crew lead, and assistant crew lead fire assignments and prescribed fire FEMO duties
Research	<1	• Co-designed with researchers at NAU a research & monitoring project to test methods, pilot collection of updated metrics, and inform prescriptions for risk reduction more adaptively under changing fire and drought envelopes. • Kept up-to-date on emerging methods, data, research findings, and knowledge impacting prescribed burns, wildfire management, etc. • Where most applicable, provided summaries of findings to fire team.
Data Collection	1	• Assisted I&M and fire effects crew with data collection on North Rim, South Rim, and at Walnut Canyon. • Formal & informal field trips to ground-truth the extent to which plot data is capturing the landscape & fire program's assumptions, examine holding lines for Rx plans, collect gps points and photographs of fuels, erosion, vegetation challenges, and other risk and resource protection variables.
Data Analysis & Reports	15	• Graphical & statistical analyses in R to support decision making & reporting • Worked with previous fire ecologist, regional fire ecologist, crew lead and assistant lead to understand and carry-out existing FFI / Excel / FFI / R / Google sheets workflows for data collection, QA/QC, analysis, and reporting. • Co-authored the Fire Ecology Annual Report. • Co-authored USFWS annual report.
GIS	2	• Served as a liaison between GRCA GIS & IMR Fire GIS • Worked with regional fire ecologist, national & IMR GIS experts to understand burn severity history, data available, and develop updated burn severity analysis process, conduct quality assurance on historical acres burned at various severities, and develop GIS dashboard on burn severity • Provided maps for USFWS and other meetings when GRCA or IMR GIS experts were not available
Supervision/ Administration	15	• Routine Program Manger responsibilities (housing, pay, JHA's, travel, etc.) • Supervised the crew lead, assistant crew lead, and seasonal crew • Developed detailed travel, work, and budget plan for fire ecology program & fire effects crew and tracked across the year

Focus Area	Percent Time	Accomplishments and Activities
		• Provided guidance for assistant crew lead to obtain a workforce development grant for a conference • Obtained a workforce development grant for myself for the IMR fuels workshop and staff ride • Worked with crew lead and assistant crew lead to update their goals in their roles and plan around them, facilitate team work etc.
Training and Conferences	8	In addition to generally required trainings: • N9042 Resource Advisor Training • IMR Fuels Workshop • Society for Ecological Restoration Annual Conference: Co-led session on planning for fire resiliency • Earth to Sky Regional Leaders Training • Staff Ride: Leadership • Supervisory Foundations I, II, and III • Alternative Dispute Resolution for Managers; Dealing with Difficult People • Other Supervisory Trainings: Managing Employee Performance; Role of the Supervisor; Employee Performance Appraisals, etc. • Grants & Cooperative Agreements • GRCA Leadership Development & follow-up courses • Various trainings on FFI, IFPRS, InFORM, IFTDSS, WFDSS • Coaching meetings & meetings with supervisor and fire program staff

Table A-3: Fire Effects Crew 2024 Accomplishments/Focus Areas

Focus Area	Percent Time[1]	Accomplishments and Activities
FMH Plots	14	• 2 new baseline measurements and 28 remeasurements at GRCA • 13 new baseline measurements at WACA in coordination w/ SCPN staff (combo FMH-I&M plots)
RAP Plots	0	• No scheduled remeasurements or immediate post-burn reads in 2024
I&M Plots	10	• 1 immediate post-burn read in Pinyon-Juniper • 13 new baseline measurements and 11 remeasurements of fuel and tree data in Mixed Conifer plots at GRCA in coordination w/ SCPN staff
Data Entry/ Management	9	*ALL 2024 plot data collected and checked electronically with tablet computers in the field; data entry and field checking are included in percent time under each plot type* • QAQC queries completed for 2024 GRCA standard (non-I&M) data • Data imported for 2021-2023 I&M PJ & Mixed Conifer data • Created new electronic data entry using FFI CSV file exports from R, Google Sheets, and tablets/phones • Includes FFI/Google Sheets electronic data prepping, merging, and checking
Data Analysis	2	• Annual Report analysis on all major variables in program completed in January 2025 • Lead and Asst authored the Fire Ecology Annual Report
Plot Office	19	• Includes plot preparation, plant ID, photo filing, tree mapping, hardcopy data filing/organization, and plot-related projects such as the new Botany Guide
General Office/ Supervision/ Admin	18	*The winter was devoted almost exclusively to office work, with both the permanent Assistant Lead and Lead focusing on tasks in the office with minimal furlough. Hence, a larger percentage of general office time than in years past is reflected* • Includes paperwork for travel, credit cards, non-plot related projects • Hiring, evaluations, and daily leadership of 3 seasonals by Asst & Lead
Fire Monitoring (Rx or Wildfire)	2	• Lead FEMO & FEMO trainee on 2 Rx fires at GRCA and North Zone
Fire Operations/ Assignments (Rx, Wildfire, Engine, Helitack, Non-fire Fuels Projects)	14	*Includes all collateral duty time on Rx or Wildland Fire operations (excluding FEMO)* • Crewmembers assisted Fire Archeologist with READ/REAF surveys for multiple days • Asst went on READ/REAF assignment for 2 weeks in NM • 3 crewmembers went on READ/REAF trainee assignments for 6 weeks in NM, AZ, CA, & ID • ICT5, FFT1-t, and FFT2 support on total of 4 North Zone & GRCA fires • FAL3-t and FAL2-t support for North Zone Rx fire prep for multiple days • Cross-trained crewmembers with North Zone module and fuel sampling
Training	7	• All attended annual fire refresher • Asst attended AFE Fire Ecology Conference in New Mexico • 1 completed S212 • 1 completed S290 • 1 completed S390 • 2 completed N9042 • 1 attended N Rim Technical Search & Rescue training • ~5% of crew time spent on PT
Travel Away from Duty Station	–	• ~1 month total for crew spent on South Rim and at WACA for plot work & training • ~4 months for crew lead teleworking in Flagstaff & detailed at ROMO • ~3.5 months for assistant crew lead dual-duty stationed at South Rim
Other	5	• Assisted N Rim vegetation staff for multiple days • Asst Lead participated in GRCA vegetation river trip for 9 days • ~13% of crew time spent on leave or holidays not worked[2]

[1] 1008 hours of combined overtime and comp time, equaling 13 percent of total crew work time (base + OT + CTE), are not reflected.
[2] Leave taken and holidays not worked were included in focus area percentages of time in previous annual reports. The percent listed here is provided for reference to compare to prior reports, but is not included in the percentage calculations listed for major duties.

Appendix B. Fire Ecology Challenges & Accomplishments Narrative

Fire Severity Tracking Stalled

Upon onboarding, the Fire Ecologist learned that prior reports to the USFWS that employed the strategy of using standard MTBS fire severity categories (high, medium, low) had not been well received since it did not meet GRCA's needs and commitment to track fire severity, particularly in sensitive MSO habitat areas, within four meaningful categories (high, moderately high, moderately low, and low) that affect outcomes, and that the annual report to USFWS for which this was needed was due. This issue posed challenges to continued prescribed burns and other preparedness activities, because the percentage of area that can or should burn at moderately high or high severities, for a variety of reasons, must be monitored and adaptively managed.

Historically, after MTBS switched to a three category system, an on-site GRCA Fire GIS expert utilized the CBI method (Key & Benson 2006) to further refine fire severity on the ground after receiving MTBS data (Eidenshink et al. 2007). However, this method was no longer available due to staff reductions and consolidation of Fire GIS personnel to the regional/national levels. Crucially, our Regional Fire Ecologist and previous GRCA Fire GIS Specialist and Fire Ecologists kept clear records of how the CBI data collected on the ground had been used to translate the remote sensing MTBS data into four fire severity categories, and the metrics of how this translation resulted in the required categories. This translation is a crucial step for informing preparedness and management for a couple main reasons: MTBS had started out using four categories but then moved to three, and remote sensing data is known to require more local, regional and seasonal translation, since it may not adequately account for factors that tend to be more localized such as vegetation type, and the topographical, temporal and geographic impacts and constraints to regional or national events such as droughts.

To find a path forward, the Fire Ecologist imported previous records on the CBI/MTBS data translation into the modern analysis software package known as R and R studio suite (R Core Team 2023) and was able to provide visual and statistical evidence for how the MTBS three category classification system could be reliably translated into the needed four category system, based on existing historical ground-truthing data. A photo-documented definition of the four categories as they were originally outlined, and explanation of the process for translating MTBS data moving forward was outlined and provided to USFWS in the annual report. It is important to note that this does not mean that future on the ground CBI refinements of MTBS data are not needed. The future will not look like the past, so continued calibration of remote sensing data and validation of it on the ground in the future will be necessary. However, using this method identifies a path forward for the present, and allows for more intermittent on the ground calibration and validation of remotely sensed MTBS data. For a more detailed explanation, please see the CY 2023 Annual Section 7 Fire and Fuels Report (NPS 2024). The method utilized is also depicted below in **Figure 1**. The new method for calibrating MTBS data proved acceptable to USFWS and the GRCA fire program. As a result, the GRCA Fire Program was able to move forward with its required tracking and reporting of high and moderately high severity fires, especially as they pertain to sensitive habitat, as required by the Biological Opinion (USFWS 2009) and other requirements of the Fire Management Plan.

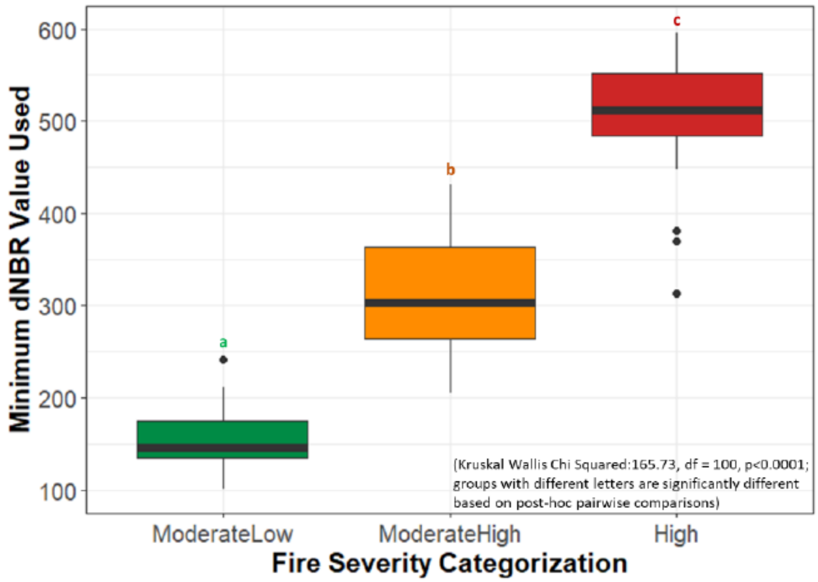

Figure 1: Boxplots of minimum dNBR values historically used to categorize moderately low, moderately high, and high burn severities at GRCA, based on ground truthing using CBI methods and the definitions provided in the FMP Biological Assessment (NPS 2009). In accordance with this method, the medians of these minimum dNBR values (represented by the thick lines in the middle of each boxplot) are now used to translate MTBS data into the required four categories of fire severity for monitoring and adaptive management. To be informative for management, planning, and preparedness, this method still requires intermittent validation on the ground using CBI methods. However, this strategy balances the ground truthing effort required with program staffing, priorities and workloads.

Prior Severe Fire Impacts

During discussions with USFWS and SRM staff while addressing fire severity tracking challenges and discussing 2023 annual reporting, additional concerns regarding the status of fuels and ecosystems on the North Rim emerged. Once concern in particular rose to the top. Data and systematic photo point documentation revealed that in certain areas on the North Rim, forests which used to be high quality ecosystems providing valuable services for visitors, drinking water supplies and habitat for sensitive species which are also park attractions, were now so altered from their initial condition as to lack most of their initial values. Further investigation into fire effects plot data demonstrated that previously high functioning mixed conifer areas on the North Rim had been reduced to near monocultures of dense, small diameter, prickly seas of aspen and locust. Plot photos and data demonstrated that these areas now had little resource value, were inaccessible to the point that firefighting would be highly impeded, and were such large areas with such altered characteristics that they would not recover without intervention. If left unaddressed, the issue would reduce habitat and resources GRCA is required to protect, and impact fire management and preparedness capabilities, increasing risk and decreasing fire preparedness.

Research into these areas revealed that they had been burned at moderately high and high severities twice within 16 years (Outlet and Fuller fires, 2000 and 2016), and plants dependent on seed for reproduction were nowhere to be found within the large perimeters. Due to the eradication of seed banks, and likely microbial soil communities, within the fire scars, and biological and dispersal limitations, intervention would be needed to restore both seed-dependent plants and soil microbial communities that confer drought and fire resilience to small, strategically selected areas within the larger affected area perimeters, breaking up the continuous, dense, fine fuels. The Fire Ecologist worked with USFWS, SRM, and the FMO to develop a proposal to accomplish this, and author a modification to the Fuller Fire BAER report. A proposal was submitted to enable the use of BIL/BAER/BAR funding for this purpose, and incorporate the most innovative, evidence-based techniques such as the utilization of topography for strategically needed microclimates and the restoration of soil biota along with native vegetation. GRCA's BAR modification and funding request were funded. However, before the project could be awarded, the funding was affected by a widespread funding paused. Currently, the spending of some of this type of funding has resumed, but projects above $50,000 (which includes this one) must go through a new review process. Guidance, process and timeline for the new review process remain elusive. However, we have been provided with guidance instructing that fuels fire preparedness projects such as this one are exempt from the additional review process, so we are hopeful the project will more forward in a timely manner, since the project itself will not be able to absorb much further delay due to funding constraints on the finish date (9/30/2026). All project documents and justifications, and the purchase request number have been submitted in FAST.

Modernizing & Streamlining Workflow

During discussions regarding the fire severity tracking challenges, the Fire Ecologist began assessing the best method for importing data from the national FFI databases into the R and R Studio suite for analysis, going over processes required for electronic data collection and for QA/QC of data in FFI and R with GRCA's Crew Lead and Assistant Crew Lead. During these discussions, several challenges emerged to effectively and efficiently leveraging the vast array of existing data to inform fire planning and preparedness. These challenges can largely be summarized as workflow and data management issues: 1) Data must currently flow back and forth multiple times through FFI, MS Excel, Google Sheets, FFI Toolbox queries and reporting, and eventually R at each of the three major steps: data collection, QA/QC, and analysis and reporting. 2) Additionally, this is true for each different FFI database that GRCA and Northern Arizona parks and monuments have, and each different plot type and metric type, multiplying the steps currently required. 3) Additionally, the existing process means that data resides in multiple locations (leading to errors since any updates must be completed multiple times). 4) And most changes and corrections must be implemented by hand each time (rather than by code that can easily be tweaked to accommodate a new year and re-run, creating ample opportunities for human editing mistakes to occur).

The current workflow was cutting edge when it was developed. However, the four characteristics mentioned above are, as a best management practice, generally avoided by experienced managers of large databases today for the reasons stated above. They are also the main factors currently precluding broader and more innovative uses of Fire Ecology program data to more fully inform fire planning, adaptive management, and preparedness. This is urgently and direly needed, particularly as the baseline conditions on the ground change with extended droughts, making accurate, up-to-date data and analysis even more necessary to inform decisions. In addition, leveraging and harnessing the full power of this data will be needed to update the Fire Management Plan, the Monitoring Plan, and innovate strategies to respond to emerging conditions, reduce risk, and increase effectiveness and efficiency.

If shifting conditions are not planned for and addressed, including modernizing and leveraging all existing data in this way to inform adaptive management, risks to the treasures of Grand

Canyon National Park could increase. For example if a broader analysis of the data has not occurred, GRCA will continue to be unaware of vegetation changes occurring which may make existing fire management strategies inappropriate and outdated, potentially leading to situations where incorrect prescriptions are used or the risk of wildfires is incorrectly assessed.

Figure 2 below summarizes the multiple steps back and forth between various software packages that characterize the existing workflow and limit innovative uses of the data and the use of the efficient, flexible, repeatable nature of R and R Studio suite. For example, analyses of many kinds can be coded in R, updated with a new year of data or new time specifications and re-run annually with improved statistical and graphical capabilities, incorporating currently un-used and under-utilized existing data. R Markdown provides a methodology for running the code once and automatically generating reports and presentations. The flexibility of R code and open source routines and sub-routines known as packages allow introducing modern statistical calculations that can deal with skewed data or other problems efficiently whenever needed, interfacing data with geographic summary and other GIS capabilities, and creating predictive models based on existing data on the ground.

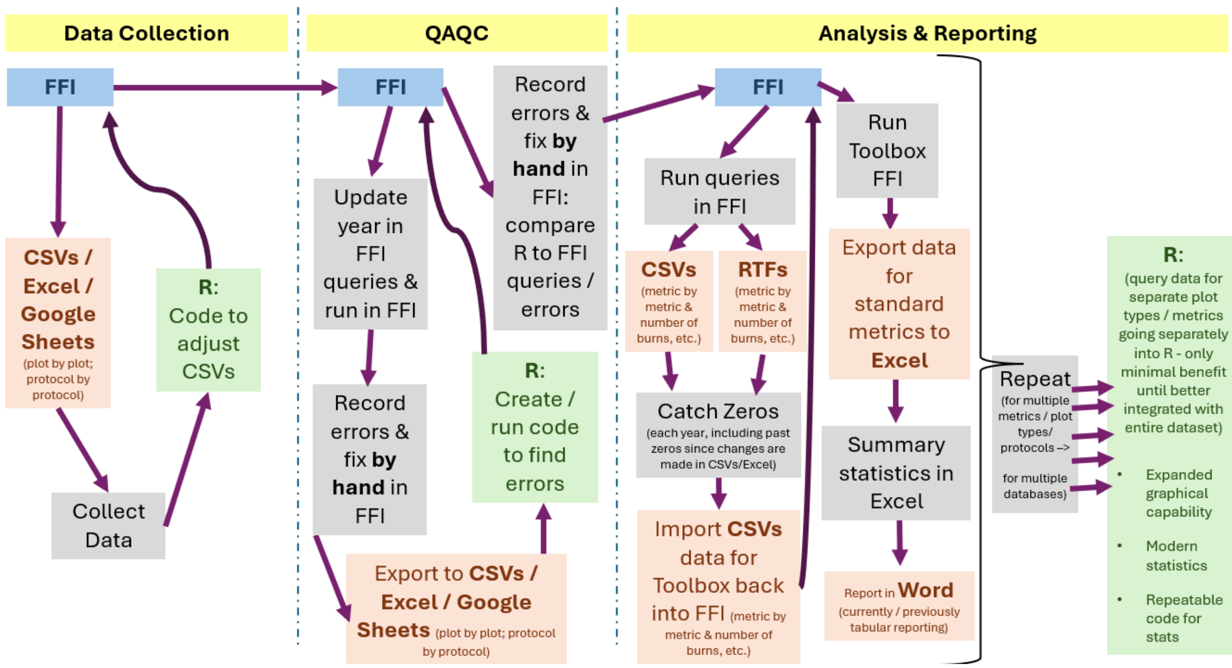

Figure 2: A depiction of current fire effects plots data and fire ecology program analysis workflow, identifying multiple places where data is stored and potential sources of error introductions.

To accomplish this transition efficiently requires understanding the table and join structure of the existing FFI database and obtaining the tables of data once per year from FFI developers, while retaining FFI as the source of record, FFI analytical capabilities for standard measures and/or parks or staff who do not wish to learn or use R, and other FFI value-added functions. To accomplish this, we requested the following from regional and national database managers:

1) We need the backend tables to be shared;
2) We need the CSV files each year rather than the FFI-only backup table so the data is accessible and all data fields are known;
3) We need an outline of how the backend tables are joined together within the database to ensure full but non-duplicative storing of data.

FFI is an enormous, multi-agency database with a number of sub-databases specific to location and data type, facts which are both part of its amazing utility and what makes a prospect like this challenging. However, we anticipate that the request from GRCA itself (beginning with only GRCA databases/plot types and not those for outlying monuments) would be an efficient, sensical place to begin, for the following reasons:

1) Databases generally have this backend or internal structure (rather than the external data entry and querying shells that FFI users currently see) so it should already be established (and is already likely described or depicted somewhere) and just needs to be shared.

2) GRCA already obtains a backup file of our database once per year. However, it is currently received as files that can only be backed-up to FFI. Thus, the yearly export could be adjusted to provide an export of the database tables into CSV files so that they can be utilized with other programs besides FFI and can be shared along with the information on what fields in each table are used to link across tables. This would have the added benefit of making the data collected by our program transparent to the public and people we serve, and widely available for other researchers and uses, creating significant value added.

3) CSV files obtained yearly will naturally feed into the preparation for data collection the coming season, immediately decreasing the back and forth at the QA/QC end of the workflow.

4) CSV files obtained yearly will naturally feed into the annual analyses and reporting, immediately reducing effort to guess that the database structure in R should be, and the needed back and forth to obtain the data for analysis.

Additionally, using GRCA as a test case for this evolution is an effective and efficient pilot program due to:

1) GRCA's R coding workforce and expertise (Fire Ecologist and Assistant Crew Lead) and FFI expertise (Crew Lead) available to work as a team with FFI developers, and to create and test R code for sharing with other parks and users.

2) GRCA's relatively wide variety of databases and plot types, useful to identify where tools and code created for one database or plot type will need adjustment to make it implementable for other parks or users once shared. At GRCA, we can begin this effort with one database / plot type, create code, and then test the transferability of that code the identify the steps needed to update the code for additional parks by testing the transfer to other databases and plot types within our own program. This represents a significant advantage in time and efficiency for not only providing a process useful to GRCA, but also identifying and implementing processes for transferability to other programs, all under one roof with existing staff who understand the intricacies of all the different types of data.

Figure 3 illustrates an example of the type of table and join structure typical of databases, which is needed from FFI developers for GRCA databases (top). Figure 3 also depicts an example of a future desired workflow which is efficient and effective, incorporating tables obtained directly from FFI and implemented in R with the join instructions provided by FFI developers. To identify and seek help with this challenge, and illustrate a path forward, GRCA's Fire Ecologist and Assistant Crew Lead presented these challenges and proposed path forward to the R + FFI working group in February 2025, and submitted the request for information from FFI developers to regional and national NPS leaders and the USFS who leads work and developers on FFI during 2024.

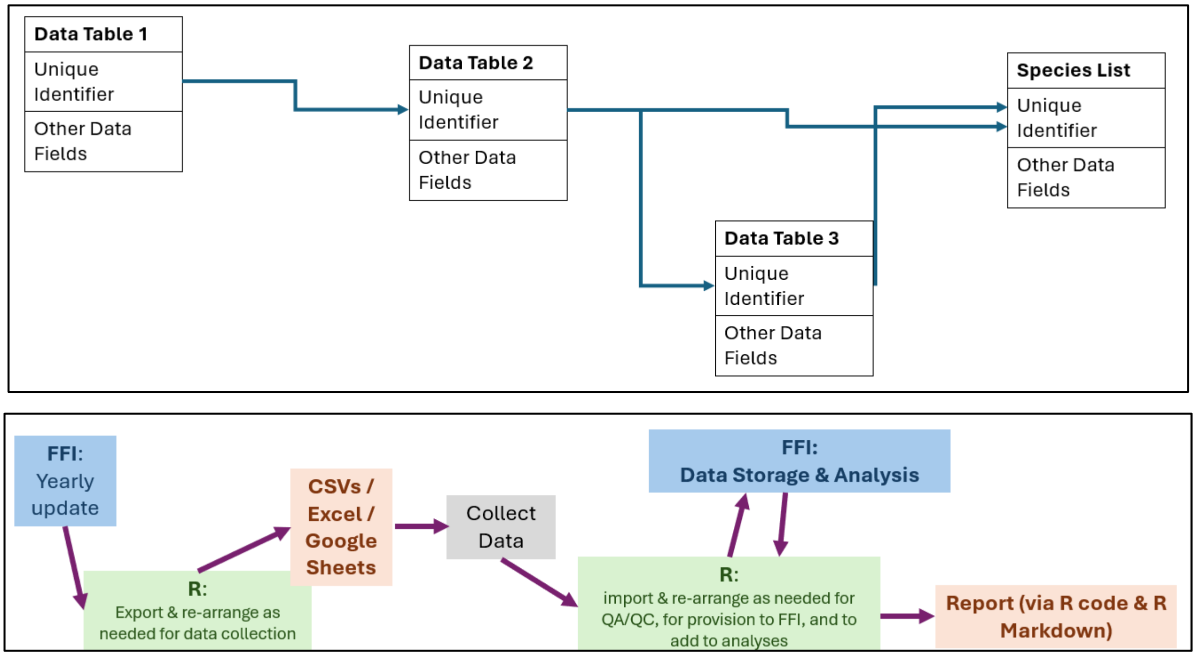

Figure 3: Example of the table and join structure typical of most databases, being requested from FFI for use in R to avoid duplicating effort to recreate the database structure in R (top), and an example of GRCA's future workflow goal, needed to leverage existing and ongoing data and inform crucial risk evaluation and decision-making.

Due to the crucial and relatively urgent nature of this challenge with implications for fire preparedness and adaptive management under the shifting conditions we face, and the fact that this task is a necessary step in informing adaptive management to minimize risk to people and resources at the Grand Canyon, the GRCA Fire Ecologist took additional action on this challenge. Additional R and statistical analysis expertise and labor would move the program forward on this central challenge in an urgent manner. As a result, the GRCA Fire Ecologist developed a statement of need for financial assistance from the USGS/NPS Natural Resources Preservation Program. The statement of need was developed jointly with local staff at USGS who specifically have extensive R, data management, and modern statistical and modeling expertise, and would work collaboratively with the Fire Ecologist, Crew Lead, and Assistant Crew Lead to move GRCA's Fire Ecology program forward on this goal in a manner responsive to the central nature of this challenge to human and resource safety. Given the current nature of funding pauses, it remains unclear whether this crucial and urgent project will receive the funding needed to move it along in an appropriately urgent manner. GRCA staff will do their best to move it forward within existing staff and resource limitations.

<u>Identifying Innovative Strategies for Shifting Fire Conditions</u>

The Fire Ecologist reviewed changes occurring landscape conditions and risk assessment and mitigation techniques for future fires with the FMO, SRM, USFWS and a variety of partners. During these conversations, it became apparent that GRCA decision-making to incorporate shifting drought and fire conditions had not begun. Updating this decision making requires a convergence of three lines of effort: 1) updating our data analysis and reporting capabilities to understand current and expected conditions specifically at GRCA (addressed above), 2) summarizing knowledge of risks and available innovations from studies, and 3) updating risk assessments, goals and strategies across GRCA landscapes. Innovations expected to reduce those risks and complement or substitute for prescribed fires along with their tradeoffs use must be explored and summarized, and it must be identified when and where each innovation is efficient, effective and appropriate based on knowledge of its utilities and risks. Due to the urgent nature of shifting conditions and the risks they pose, the effort required to accomplish 1 (addressed above), and the existing workloads and duties of GRCA staff, the Fire Ecologist worked collaboratively with SRM and the approval of the FMO to seek funding for an intern to specifically assist with steps 2 and 3. The Fire Ecologist successfully submitted and was awarded financial assistance from the Scientist in the Park program and the Grand Canyon Conservancy for an intern to complete these tasks. During the hiring process, the program was suspended indefinitely pending review of the Scientist in the Park program. Review guidance, process, and timeline still appear uncertain. GRCA is standing by to learn more and investigating other avenues to achieve this goal, given the urgent nature of these tasks to inform fire management, planning, and preparedness.

Addressing Data Gaps

The RM 18 outlines identifying and addressing information gaps to improve management capabilities as crucial to informing and supporting informed fire management and activities. The RM 18 prioritizes identifying critical studies that directly address information gaps needed to improve management activities, that will inform park management decisions. Such studies provide crucial data and techniques to improve fire behavior predictions, assess treatment effectiveness and risk to people, communities, and valuable resources, and help predict how changes in baseline conditions impact fire behavior, risk, and outcomes.

Upon onboarding, the Fire Ecologist learned of significant data gaps surrounding how advances in science inform fire risk factors that are crucially important as baseline conditions out on the landscape (such as extended droughts, increasing severity of floods, etc.) shift. These data gaps are crucial to both risk assessment and management, because they inform what treatment designs reduce risk best, what unanticipated effects to expect, and whether prior assumptions about fire preparedness and risk are still accurate. Incorrect information about risk and management could eliminate resources valuable to people and wildlife and increase fire risk instead of decreasing it. For example, as soil moisture conditions shift, prior models calculating fire risk and spread from vapor pressure deficit (VPD) and wind speed will become outdated without additional information on how extended droughts are affecting soil moisture and even more directly the water stress status of plants/fuel. As a result, addressing these data gaps, and testing which updates to data collection are most crucial for preparedness and risk assessment represents a crucial step.

The Fire Ecologist designed a project to collect information addressing these data gaps (and test which are most efficient and important to incorporate into the Fire Ecology program) in conjunction with a fuels management project and submitted the proposal as a Reserve Fund Research Request (a fund specifically intended to address challenges to fuels treatments and FMP revisions). GRCA awaits updates on funding availability and continues to consider other potential avenues to address this challenge.

Appendix C. Additional Research & Publications

Below is a more comprehensive list of publications since 2020 involving research related to fire based on data gathered in or on lands adjoining Grand Canyon National Park without direct contributions from personnel or data within the GRCA Fire program, but whose results could have applicable management implications across boundaries. Citations for these works are as follows:

- Aslan CE, Zachmann L, McClure M, Sikes BA, Veloz S, Brunson MW, Epanchin-Niell RS, Dickson BG. Quantifying ecological variation across jurisdictional boundaries in a management mosaic landscape. Landscape Ecology. 2021 Apr;36:1215-33.
- Aslan CE, Zachmann L, Epanchin-Niell RS, Brunson MW, Veloz S, Sikes BA. Soil characteristics and bare ground cover differ among jurisdictions and disturbance histories in Western US protected area-centered ecosystems. Frontiers in Ecology and Evolution. 2022 Dec 23;10:1053548.
- Aslan C and Souther S. 2022. The Interaction between Administrative Jurisdiction and Disturbance on Public Lands: Emerging Socioecological Feedbacks and Dynamics. Journal of Environmental Management. 319:1-10
- Bahin CC. *Fire effects on cultural resources in Grand Canyon National Park* (Master's thesis, Northern Arizona University). 2023
- Baker WL, Hanson CT, Williams MA, DellaSala DA. Countering omitted evidence of variable historical forests and fire regime in western USA dry forests: The low-severity-fire model rejected. Fire. 2023 Apr 3;6(4):146.
- Burch SJ. *Assessing Fire Impacts to a Spring-Red Riparian Ecosystem During a Dry Climate Cycle in Grand Canyon National Park, USA* (Master's thesis, Northern Arizona University). 2021
- Coop JD. Postfire futures in southwestern forests: Climate and landscape influences on trajectories of recovery and conversion. Ecological Applications. 2023 Jan;33(1):e2725.
- Crouch CD, Rogers PC, Moore MM, Waring KM. Building ecosystem resilience and adaptive capacity: a systematic review of aspen ecology and management in the Southwest. Forest Science. 2023 Jun 1;69(3):334-54.
- Donager JJ, Sánchez Meador AJ, Huffman DW. Southwestern ponderosa pine forest patterns following wildland fires managed for resource benefit differ from reference landscapes. Landscape Ecology. 2022 Jan 1:1-20.
- Jackson S, Hitchner M, Ritchie M, Miotke J. Grand Canyon Ecological Forecasting: Using NASA Earth Observations to Monitor and Model Juniper Woodland Mortality in Grand Canyon National Park.2022
- Lawrence DJ, Tercek M, Runyon A, Wright J. 2024. Historical and projected climate change for Grand Canyon National Park and surrounding areas. Natural Resource Report. NPS/NRSS/CCRP/NRR—2024/2615. National Park Service. Fort Collins, Colorado. https://doi.org/10.36967/2301726
- Liang S, Hurteau MD. Novel climate–fire–vegetation interactions and their influence on forest ecosystems in the western USA. Functional Ecology. 2023 Aug;37(8):2126-42.
- Munson SM, Vaughn AL, Petersen B, Bradford JB, Duniway MC. Natural resource management confronts the growing scale and severity of ecosystem responses to drought and wildfire. Ecology and Society. 2024 Nov 31;29(4).

- Oliver S, Shadroui T, Novick E, Lee Y. Adapting to Climate Change Impacts on the Colorado River in Grand Canyon National Park. 2022
- O'Neill L, Fulé PZ, Hofstetter RW. Multi-Century Reconstruction of Pandora Moth Outbreaks at the Warmest/Driest Edge of a Wide-Ranging Pinus Species. Forests. 2023 Feb 21;14(3):444.
- Phinney AI. *Investigating the Use of Quartz Luminescence and Rock-Color Alteration to Characterize Wildfire Exposure; Applied to the 2020 Mangum Fire, Kaibab Plateau, Arizona* (Master's thesis, Utah State University). 2022
- Roccaforte JP, Huffman DW, Rodman KC, Crouse JE, Pedersen RJ, Normandin DP, Fulé PZ. Long-term ecological responses to landscape-scale restoration in a western United States dry forest. Restoration Ecology. 2024:e14181.
- Springer JD, Stoddard MT, Rodman KC, Huffman DW, Fornwalt PJ, Pedersen RJ, Laughlin DC, McGlone CM, Daniels ML, Fulé PZ, Moore MM. Increases in understory plant cover and richness persist following restoration treatments in Pinus ponderosa forests. Journal of Applied Ecology. 2024 Jan;61(1):25-35.
- Stan AB, Fulé PZ, Hunter Jr M. Reduced forest vulnerability due to management on the Hualapai Nation. Trees, Forests and People. 2022 Dec 1;10:100325.
- Stoddard MT, Roccaforte JP, Meador AJ, Huffman DW, Fulé PZ, Waltz AE, Covington WW. Ecological restoration guided by historical reference conditions can increase resilience to climate change of southwestern US Ponderosa pine forests. Forest Ecology and Management. 2021 Aug 1;493:119256.
- Sullivan III AP, McNamee C, Wendel M, Mink PB, Allen SE. Archaeological evidence of anthropogenic burning for food production in forested uplands of the Grand Canyon province, northern Arizona. Frontiers in Environmental Archaeology. 2024 Sep 4;3:1302604.
- van Mantgem PJ, Falk DA, Williams EC, Das AJ, Stephenson NL. The influence of pre-fire growth patterns on post-fire tree mortality for common conifers in western US parks. International Journal of Wildland Fire. 2020 Feb 6;29(6):513-8.
- Young JD, Ager AA, Thode AE. Using wildfire as a management strategy to restore resiliency to ponderosa pine forests in the southwestern United States. Ecosphere. 2022 May;13(5):e4040.

Top: 2024 Grand Canyon Fire Effects Crew
Bottom left: SCPN & Fire Effects partnering on the North Rim
Bottom right: Monitoring on the Cape Final Rx
(photos by NPS)