Saguaro National Park

Desert Hazardous Fuels Treatment Report 2011-2022

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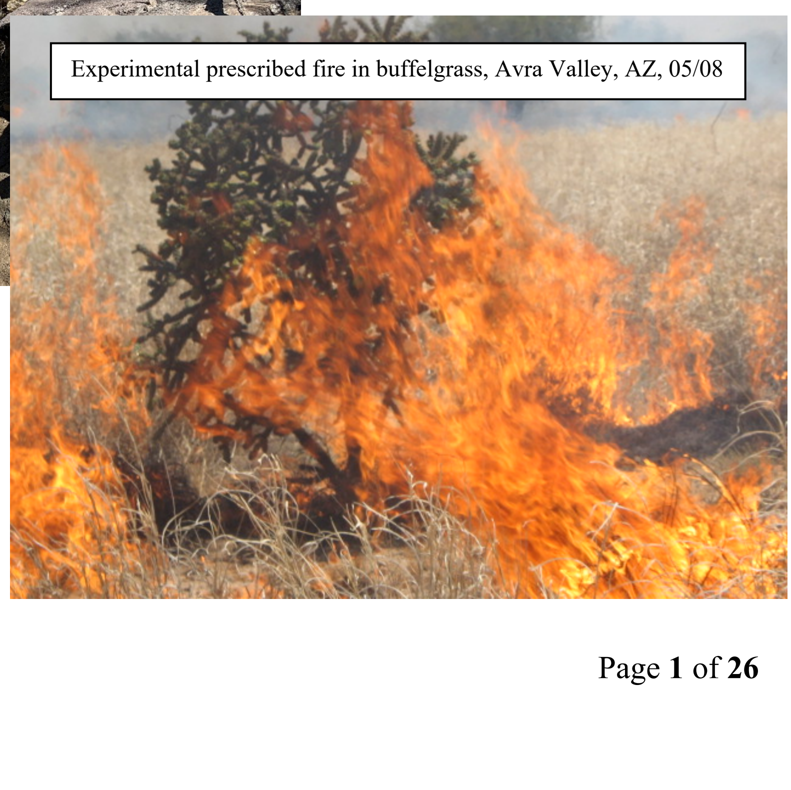
Buffelgrass along the Arizona Trail, SNP, 02/22



Experimental prescribed fire in buffelgrass, Avra Valley, AZ, 05/08

Contents

Executive Summary

This report describes recent, current, and future management of invasive species that can create hazardous fuels in the Sonoran Desert portion of Saguaro National Park. The main threat at present and the main treatment target is buffelgrass. The environmental damage and risk from fire that it causes are well documented. There are a few other non-native, invasive species that also increase fuel load and connectivity: chiefly warm season perennial grasses and a newly introduced winter annual. A significant portion of the funding for managing these species in Saguaro NP comes from DOI NPS Hazardous Fuels Funds.

1. Introduction

The survival of the Saguaro cactus, the park's namesake, is threatened by invasive plants that create fuel continuity and build heavy fuel loads, principally buffelgrass (*Pennisetum ciliare*, syn. *Cenchrus ciliaris*), along with other fire-tolerant invasive plants. Saguaro National Park (SNP) was established in 1933 to preserve and protect saguaro cacti, diverse biotic communities, cultural and archeological features, and scientific, scenic, and wilderness values. The park is 92,404 acres, including 71,604 acres of designated wilderness, and about 45,000 acres of the park are Sonoran Desert habitat, where historically fire was rare. Sustained, strategic effort against highly flammable invasive species is required to ensure the protection of park resources in desert areas.

Fire-tolerant invasive plants either directly or indirectly threaten many important park resources, including cultural resources. Buffelgrass burns hot enough to spall rocks, destroying rock art, and degrade some rock artifacts, ceramics, and bone (see Ryan et al. 2012). Although buffelgrass is the primary threat, SNP has identified and targeted several other invasive plant species for treatment due to their ability to spread wildfires: fountain grass (*Pennisetum setaceum*), tickgrass (*Eragrostis echinocloidea*), Natal grass (*Melinis repens*), Sahara mustard (*Brassica tournefortii*), and salt cedar (*Tamarix* species). A new threat that is causing significant damage around Phoenix, AZ, and the Tonto National Forest, AZ, is stinknet (*Oncosiphon pilulifer*). Tickgrass and Natal grass are often found in close association with buffelgrass patches. This report focuses mainly on buffelgrass since it has been such a major part of park treatments.

Buffelgrass has been identified as one of the world's most notorious invaders (Williams and Baruch 2000). It readily replaces native plant species through competition for water and light (Marshall et al. 2012) and may be allelopathic (Hussain et al. 2011). It is such a strong competitor that no native plant has been found able to outcompete it, so restoration efforts alone are not effective at maintaining native plant communities. Suppression of buffelgrass, and the other grasses which act similarly, is necessary. Recent research in the park (Gornish et al. 2020) has found that buffelgrass alters the microbiome of the soil, enhancing conditions for its growth while putting native plants at a competitive disadvantage.

In this area, buffelgrass is documented as doubling in abundance every three to seven years (Olsson et al. 2012), and aerial surveys in the park provide data that mirrors that finding (see Section 5). Buffelgrass creates continuous, heavy fuels that can feed large, intense fires, which many desert plants and animals did not evolve with (McDonald and McPherson 2011, 2013). These plant communities can take decades to recover from even mild fires (Esque et al. 2007). The Sonoran Desert typically contains light fuel loads, with bare ground between perennial plants. Invasive plants, especially grasses, fill in these spaces with highly flammable material.

Desert fires kill saguaros, other cacti, paloverdes and other native plants; however, invasive grasses respond positively to fire. Buffelgrass competition is limiting establishment of saguaros in remote areas of the park, and coupled with fire, has the potential to cause the local extirpation of the park's signature species. NPS documents discussing the need to manage invasive plants include the park's Fire Management Plan (2022) and General Management Plan (2008). The park's Restoration Plan and EA (2014) describes the invasive plant threat in specific terms and authorizes use of helicopter treatments.

Although SNP has not had a wildfire burn in buffelgrass yet, it is just a matter of time. There have been numerous fires involving buffelgrass on nearby lands including along roadways, on private lots across the Tucson basin, and in the Santa Catalina Mountains (see Wilder et al. 2021). Research in this area and modeling by USGS all show that buffelgrass can convert the Sonoran Desert into a grass-dominated vegetation type, promoting wildfires that would be catastrophic to native plant and animal species. USGS modeling also shows the increased monetary cost and decreased odds of success from delaying treatment. Beginning in 1993, the park began work to slow and reverse the spread of buffelgrass, and has had success in targeted areas. However, we have been unable to reach all infestations in the park.

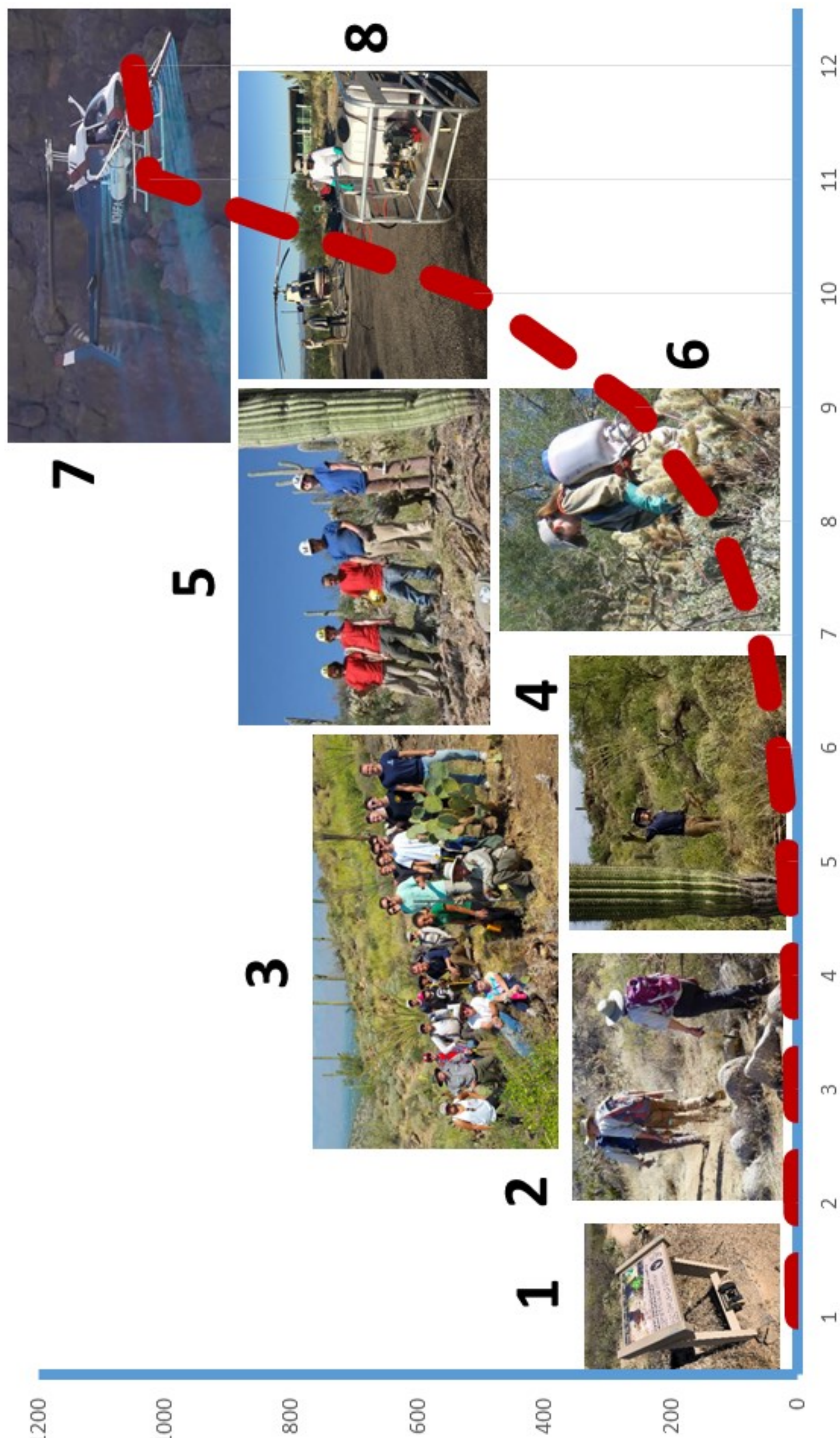
THE FUTURE OF SAGUARO NATIONAL PARK?
Burned buffelgrass on 'A Mountain' (Sentinel Peak, Tucson, AZ).

2. Strategies Used

Table 1. Strategies we use, who implements them, and comments. Discussed further below.

Prevention	***Staff, volunteers***	***Low cost/high benefit.***
1a. Education	Boot brush stations, outreach.	Prevent problems before they start.
1b. Early detection	Volunteers with botany skills and community-based observations for early detection of new invasive species in or near the park.	Little supervision required, best tool for new invasive species. Monitor apps such as iNaturalist and EDDmaps.
Mechanical Removal	***Staff, conservation corps, and volunteers***	***High labor requirement per acre treated. Significant soil disturbance.***
2a. Weed Free Trails (WFT)	More highly trained volunteers functioning largely independently along trails.	Less supervision required. Good for new introductions, not for off-trail colonies.
3a. Special Events	Select groups of volunteers invited (military, corporations, youth groups, conservation groups, etc.)	High supervision/leadership requirement.
3b. Regularly Scheduled Events	General public invited to scheduled volunteer pulls.	High supervision/leadership requirement. Highly restricted by distance and terrain.
4. Off-Trail Volunteers (OT)	More highly trained volunteers functioning largely independently off-trail.	Less supervision required. Attack off-trail colonies. Higher level of fitness required than above.
2/4. Volunteer Assistants	Volunteers assisting WFT and OT Volunteers.	WFT and OT volunteers provide leadership.
5. Paid personnel	Staff, interns, conservation corps.	Highly trained, physically capable, can hike further and stay out longer.
Chemical Treatment	***Staff, contractors, conservation corps, volunteers.***	***Efficient, able to reach more remote areas, collateral damage from herbicide.***
6. Ground Chemical Treatment	Staff, a few volunteers, conservation corps with back-pack sprayers.	Ten to 30 times more efficient than mechanical methods in dense buffelgrass. Limited by distance and terrain because of weight of sprayers.
7. Aerial Chemical Treatment – Boom	Contract helicopter with boom sprayer, similar to agricultural operations.	Approximately 20 times more efficient than ground chemical treatments, but not precise. More collateral damage. Safer than ground treatments. Lowest cost/acre.
8. Aerial Chemical Treatment – Spot	Contract with a helicopter with a spot-spray apparatus. Possibly UAS in the future.	Efficiency undetermined at present. Precise. Safer than ground treatments. High cost per acre. Currently good tool for cleaning up boom-sprayed areas and the only tool for remote, newly formed colonies.

Figure 1. Different strategies listed in Table 1 and where they fit on the invasion curve (red dotted line)--from seeds just being introduced to huge monocultures. Vertical axis is a relative value of abundance. Horizontal axis is a representation of time. Invasive species increase exponentially, eventually filling all suitable habitat.



A. Mechanical Removal

i. Group Pull Events

- We typically host 13-20 buffelgrass pulls per year during the cooler months (October-April), with a few to about 50 volunteers at each (Figure 2). These are now called "buffelgrass parties."
- Significant supervision is required to maintain safety and to ensure volunteers are remove the correct species.
- The people who volunteer for these events may or may not be equipped or in condition for hiking long distances in rugged terrain.
- Most efficient follow-up is with chemical treatment during the summer monsoon season to kill emerging seedlings, which can be extremely numerous. This is very fast and very little herbicide is needed.

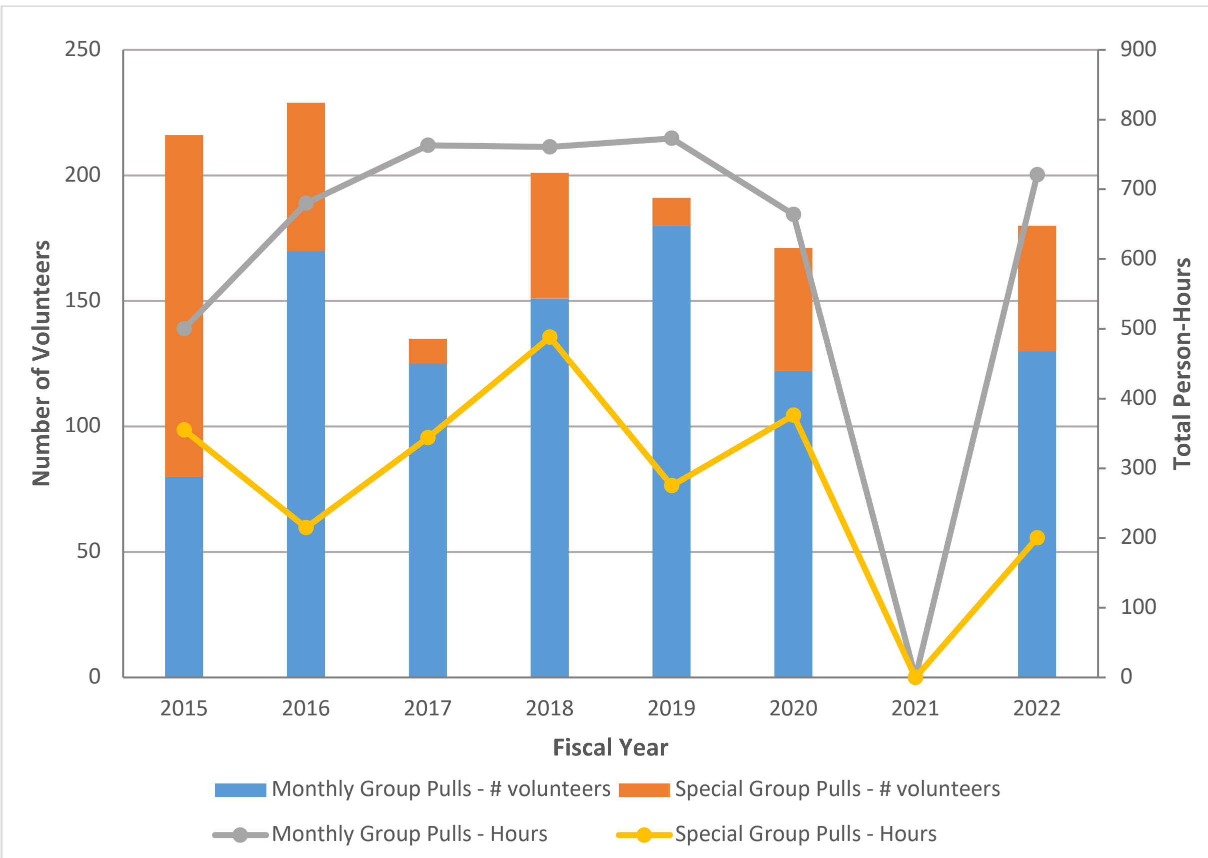


Figure 2. Total number of volunteers and person-hours worked at monthly and special group buffelgrass pulls ("parties"), 2015-2022. There were **no group events in 2021 due to the pandemic.**

ii. Weed Free Trails

- Weed Free Trails (WFT) volunteers receive comprehensive training and work independently throughout the year on their own schedule (Figure 3).
- In 2019, a WFT Assistant volunteer position was created. These volunteers receive some training from the park, and can only go in the field while accompanying the fully trained WFT volunteers.

iii. Off-trail volunteers

- This program evolved from WFT volunteers who wanted to attack buffelgrass beyond the trail corridors.
- Collectively, WFT and OT volunteers are termed "Saguaro Stewards."
- Volunteers "adopt" specific pieces of ground.
- This program is especially valuable, because we can adopt out low-density areas and infestations reduced by chemical treatment to remove them from our future re-spray workload and reduce herbicide use.

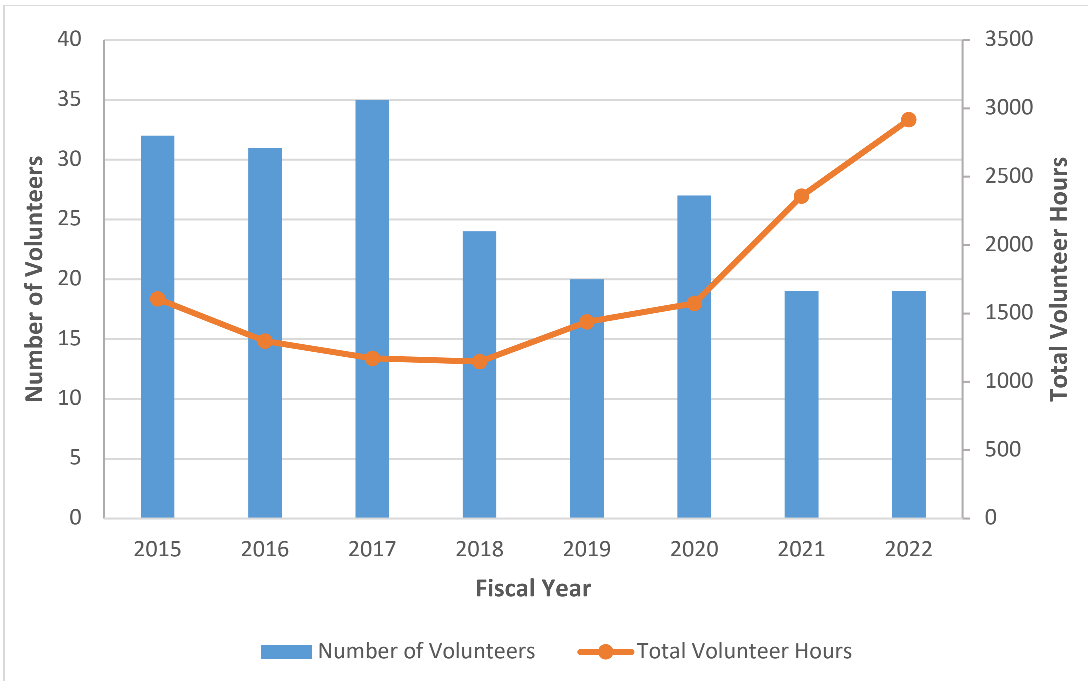


Figure 3. Total number of Weed Free Trails volunteers, WFT assistants and Off-Trail volunteers, by fiscal year, and their total hours worked, 2015-2022.

v. Staff and youth conservation corps

- We have found that mechanical removal of buffelgrass in low density areas can be as efficient on a time per acre basis as chemical treatment.
- These low density areas are either new infestations or previously sprayed dense infestations.
- It can be done during the winter with a much lower risk for heat illness.
- This is also the time of year when buffelgrass cannot be sprayed.
- It is also be used when rains fail during the monsoon (e.g., much of the summer of 2020).

B. Herbicide Application

i. Ground Spraying

- Phenology of buffelgrass and our climate present serious challenges to chemical treatment. Spotty downpours cause sudden green-up in scattered areas, and high temperatures cause rapid brown-down if later rains miss an area.
- We currently use glyphosate-based herbicides, which must be applied when the plant is actively growing and at least 50% green.
- This period is almost entirely during the summer monsoon (July-September).
- Although chemical treatments of dense patches are more efficient than mechanical removal on a time or cost per acre basis, the chemical treatment window is very short, and due to the erratic nature of the monsoon pattern, it is unpredictable.
- We have found that fountaingrass treatment success is variable and sometimes low during the monsoon. Fall-winter-spring treatments are reliably more effective, and fountaingrass is often actively growing during this time because of more moisture in drainages. This is the shoulder season of buffelgrass spray season, allowing greater focus on buffelgrass during the monsoon.
- Tickgrass and Natal grass are green under cooler temperatures than buffelgrass, and produce abundant seedlings during those periods.
- Staff, interns, conservation corps crews, and a few volunteers use back-pack sprayers.
- We use a mule pack string or helicopter to preposition water in more remote areas so that crews do not have to carry as much weight as far.
- Recently we began using ready kits that the crew carries, so that they can collect water from drainages and mix new loads without hiking back to the vehicle or a water staging area.

Figure 4. Rapidly expanding tickgrass along Old Spanish Trail, about 1 mile from the park boundary. The grass is a relative newcomer and has exploded (outside the park and within) during the last two wet summers.

ii. Aerial Boom Spraying

- In the mid-2000's, it became obvious that ground forces were unable to reach significant parts of the infestation, and buffelgrass there was increasing at an exponential rate.
- The decision to pursue aerial spraying was made, compliance was done, and the park began using aerial herbicide application in 2014 (Figure 4).
- This is done with a helicopter with a 40-foot boom sprayer for remote, large, dense patches.
    - As buffelgrass patches grow larger, native plants die off, and the largest patches are nearly monocultures of buffelgrass.
    - Relatively little collateral damage occurs, but damage to native plants increases with repeated treatments.
    - Total area treated per year climbed from 60 acres before aerial spraying to over 500 acres with aerial spraying.
  - The long-term goal is to reduce buffelgrass infestations to a level where boom spraying is no longer needed, and chemical use is greatly reduced. These areas will need follow-up monitoring and treatment, possibly from ground spraying, mechanical removal during cooler months, or aerial spot spraying.
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Figure 5. The helicopter boom-sprayer treating buffelgrass in Saguaro National Park.

iii. Aerial Spot Spraying

- The boom-sprayer is effective at reducing and breaking up large patches, but it is not precise enough to do the follow-up treatments necessary to fully achieve restoration goals.
- In 2018 the park began to use a helicopter spot-sprayer (Figure 5) to target smaller patches.
- Spot-sprayer cleans up boom-sprayed patches and is used on remote small patches while they are still a manageable size, before buffelgrass has eliminated native plants.
- Computer modeling by the USGS (Jarnevich et al. 2022) indicates that the park will lose the war with buffelgrass in the long run without spot-spraying capability (see also Moody and Mack 1988).
- It is very precise and effective, but it is costly (Figure 7). It cost approximately $1,029 per acre with the helicopter spot-sprayer in 2019.
- Aerial spot spraying might also be conducted in the future by unmanned aerial systems (UAS, a.k.a. drones), and the park is exploring this possibility.

Figure 6. The helicopter spot-sprayer operating within Saguaro National Park.

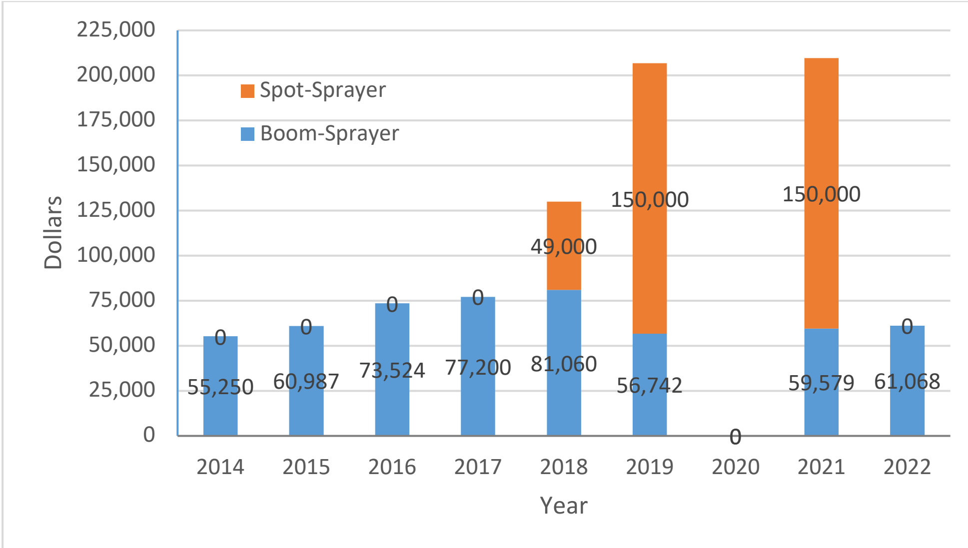


Figure 7. Annual contractor expenditures for the helicopter boom and spot-sprayers in the park. The summer of 2020 had record breaking heat and drought, and there was not enough green buffelgrass to spray aerially. The summer of 2022 had spotty rains and, in many places, very short green spray window. Boom spraying was completed, just barely. There was insufficient green-up to order the spot sprayer.

C. Monitoring

i. Treatment Mapping

- Ground crews map each treatment point or polygon, as well as areas encountered that are not treated at the time.
- Data goes into the park invasive species geodatabase, and the data is viewed or analyzed to track treatment success.
- Field observations by staff and interns are also important and considered when evaluating treatments.

ii. Systematic Ground Mapping

- Ground crews systematically map areas to locate and map new or unknown invasive plant populations to assess the need for treatment.
- Crews form a line and grid target areas, and while doing so they mechanically treat isolated plants and some small patches.
- Newly found infestations are added to the treatment optimization process.
- This can be done year-round, whenever conditions are unfavorable for chemical treatment.

iii. Aerial/Remote Mapping

- Much of the park's buffelgrass infestation is beyond the reach of ground crews, and aerial mapping is required.
- We have used USDA Forest Service Forest Health software and hardware. FS personnel trained Saguaro staff on how to use it and oversee data collection and management.

- Helicopter surveys were conducted in 2012 (using NPS project funds) and again in 2019 (mostly using NPS Hazardous Fuels funds).
- In 2019, we detected about 1,550 acres of buffelgrass out of 61,215 acres of suitable buffelgrass habitat. (despite some false positives, this is likely an underestimate)
- Due to high costs and low precision, we are exploring the possibility of using remote sensing to detect invasive plant populations, including whether a UAS could be effective. The park was selected for funding for a SCC PMIS project to investigate the use of spot spraying, potentially including UAS.
- There have been two funded attempts at mapping buffelgrass using remote sensing, and both were unsuccessful. Commercially available sensors and techniques are so far unable to reliably discern buffelgrass from native shrubby vegetation and/or rough, rocky ground. As technology changes, this may become a more feasible method.
    - Note: Researchers at Boston University are currently working independently on estimating buffelgrass greenness with a different satellite imagery and different methods.

D. Education and Prevention

- The park adjoins a community of almost one million people, and the hazardous fuels created by invasive plant species create a risk to the park as well as to the community.
- The vast majority of desert habitats within the park fall within the wildland urban interface (WUI) area as designated in Pima County's Community Wildfire Prevention Plan (2013).
- Education and prevention are necessary for encouraging neighbors to take action, improving fire safety and reducing human-caused fires, as well as for gaining support for our overall efforts, including the use of herbicide in the park.
- NPS Fire Outreach grants have been received for four years to help with this effort.
- We collaborate with other members of the Sonoran Desert Cooperative Weed Management Area, which helps amplify the efforts of all partners.
    - E.g., Save Our Saguaros month—partners reach out and advertise the events, and numerous volunteer buffelgrass pulls are held across the Tucson Basin, bringing in about 1,000 volunteers. (see www.buffelgrass.org)

i. Park Website

- We periodically update our website to reflect current invasive plant species information, status, and management strategies.
- We intend to increase the amount of content, so that we can refer social media queries to our website for further information.

ii. Social Media

- We use social media to provide timely information, including about treatment locations and times.
- This has become more important with the attention focused on glyphosate in the last few years. Replying with facts to comments of others can be time-consuming but is very important.
- SNP has over 250,000 followers on all platforms (as of December, 2022), and social media allows us to access the largest number of people on a consistent basis.

iii. Outreach Events

- We provide informational brochures and speak one-on-one with local residents.
- Recruitment of volunteers is a goal as well.

iv. Boot Brush Stations

- Currently the park has boot brush stations at three high-use trailheads.
- They consist of a set of brushes that a hiker can use to clean their boots, a tray to catch the debris, and an interpretive sign discussing the damage that invasive plants can cause and how cleaning their boots can help.
- Education is provided in addition to prevention, and both are increasingly important.
  - Education and prevention are the best tools to fight new invasive species in the Tucson area, e.g., globe chamomile/stinknet (*Oncosiphon piluliferum*).
  - Boot brushes will also help prevent re-introduction of species that we have been treating.
- In 2022 we received NPS project funding for funds over two years to install 33 boot brush stations at 33 hiking access points across both districts of the park.

iv. Neighborhood involvement

- The vast majority of the park's desert habitats at risk from grassification are within designated WUI. The park works closely with multiple neighborhoods to assist with hazard fuel mitigation.
- We use outreach to park neighbors to provide information about species identification and impacts of invasive species, especially relating to the threat of wildfire.
- We provide encouragement and technical assistance to help them take action on their properties.

E. Research

- Buffelgrass is creating unprecedented fuel conditions in the Sonoran Desert.
- Unprecedented measures have been found necessary to protect resources.
  - No other entity that we know of is using aerial spraying in Sonoran Desert habitats.
  - There are no models to follow.
  - We use best available science, monitoring, adaptive management, and research into critical topics.
- The park has funded, helped fund, or supported many research projects relating to buffelgrass biology, ecology, and treatment (see Appendix A).
- Several of these projects have been funded by Hazardous Fuels Reserve Research funds.

F. Collaboration

- Cross-jurisdictional issues require multi-jurisdictional cooperation and coordination.
- We cooperate on operations with other organizations and agencies, especially NPS Southwest Invasive Plant Management Team and US Fish and Wildlife Service Invasive Species Strike Team based in Tucson.
- We are a collaborator in the Sonoran Desert Cooperative Weed Management Area (SD-CWMA; http://www.sdcwma.org/)
- This CWMA was preceded by Buffelgrass Working Group—which was organized in 2006 and had developed the Southern Arizona Buffelgrass Strategic Plan (BWG 2008). The park was a collaborator in those early efforts.

- We also contributed to the community-driven Pima County Community Wildfire Protection Plan (https://webcms.pima.gov/cms/One.aspx?portalId=169&pageId=45265), which recognizes invasive species, especially buffelgrass, as a serious fire threat.

3. Funding and Staffing

i. Funding

- The program for hazard fuels created by invasive species is funded through a variety of fund sources that has varied over time (Figure 8).
  - National Park Service base funds (ONPS).
  - NPS Natural Resource project funds.
  - Hazardous Fuels funds.
    - First received in 2008.
    - Includes the discontinued Department of Interior Resilient Landscape (RL) Hazardous Fuel reduction program.
  - Friends of Saguaro National Park.
  - Western National Parks Association.
  - Arizona Department of Forestry and Fire Management funded a grant to Friends of Saguaro National Park for hazardous fuel reduction in riparian areas, especially fountaingrass.
- Because successful treatments require 3-5 years of treatment, funding dips cause us to lose ground in ongoing treatment areas.

ii. Current staffing

- Two permanent positions (Restoration Ecologist and Crew Leader) – ONPS base.
- Three temporary seasonal employees – ONPS base and Hazard Fuels.
- Additional Resource Division staff funded from base or project funds also assist in treatments.
  - Monsoon rains create a very short active spray season.
  - Generally 12 to 16 different staff members and interns help conduct ground-based treatments.

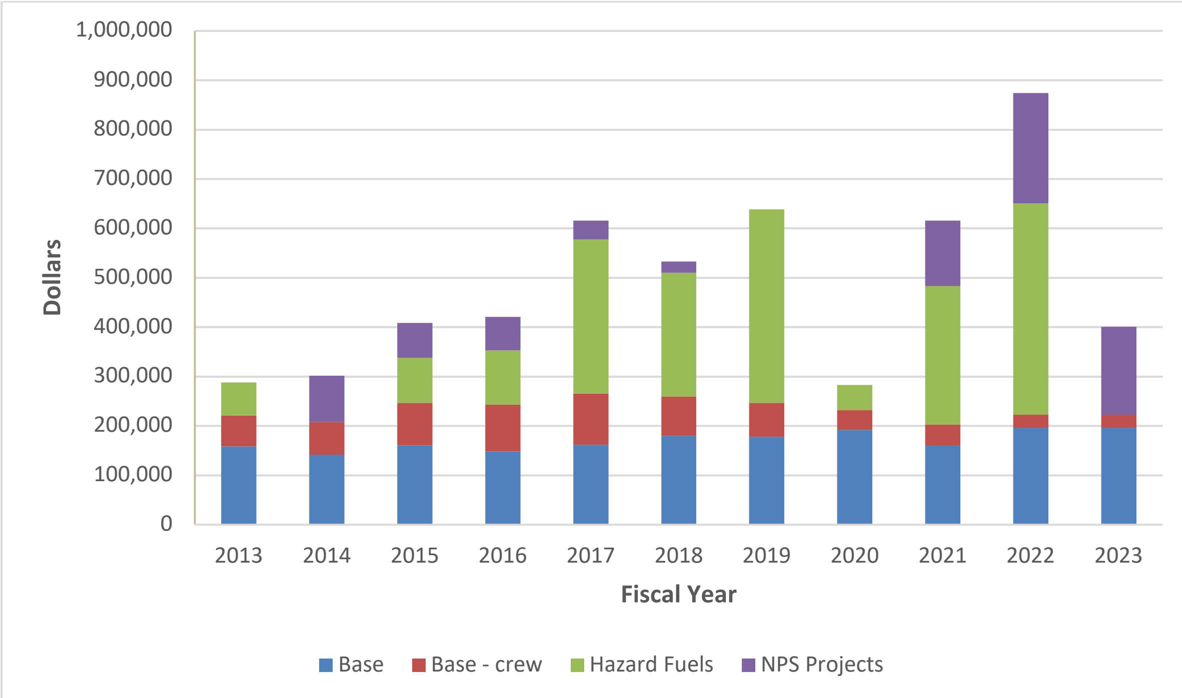


Figure 8. SNP's annual invasive plant management program budget, broken down by funding source.

In the figure above, Base is ONPS funding from park base (with "Base" being fixed costs, and "Base-crew" being non-fixed costs). Hazard Fuels funds include NPS Regional hazard treatment fuels, the former Resilient Landscapes program run by DOI, Disaster Relief (DR311), and Bipartisan Infrastructure Law (BIL) funds. Projections for FY2023 are based on the assumption that Base and Base-crew funding will be that same as in FY2022, and amounts for Project money assumes that NPS SCC-funded PMIS projects involving flammable invasive plant treatments will be fully funded.

4. Results - Acres Treated Annually

Acres treated by volunteers and staff are tracked for each treatment method (Figures 9-10; Table 1). Priorities are to work on or adjacent to previously treated areas and to work on high value habitats, such as major drainages. We also prioritize spraying archaeological sites, where manual removal is not allowed, right at the WUI, and volunteer pull patches where we eliminate buffelgrass seedlings. As a result of these consistent manual and chemical treatment methods working in tandem, large areas of the park that had been invaded by buffelgrass have now been restored to native plant communities. Because buffelgrass seeds are viable for in the soil for up to about five years, heavy infestations may take five years or more to clear.

The size of the treated area shown in Figure 9 can be misleading. For hazardous fuels treatments, treated acres are the size of the area searched where buffelgrass (and the other species; Figure 9) are killed. For example, if an area of two acres is searched and several patches covering 50% of the area are killed, two acres are reported as area treated. This most accurately reflects effort expended and is the same method that is used to determine acreage treated by thinning forest fuels.

Acreage treated fluctuates yearly depending on the precipitation pattern and available labor, which largely depends on funding. Increasing the use of WFT and off-trail volunteers increases acreage with little additional cost. Dry summers decrease the area treated chemically, because when buffelgrass is not green it is not susceptible to glyphosate.

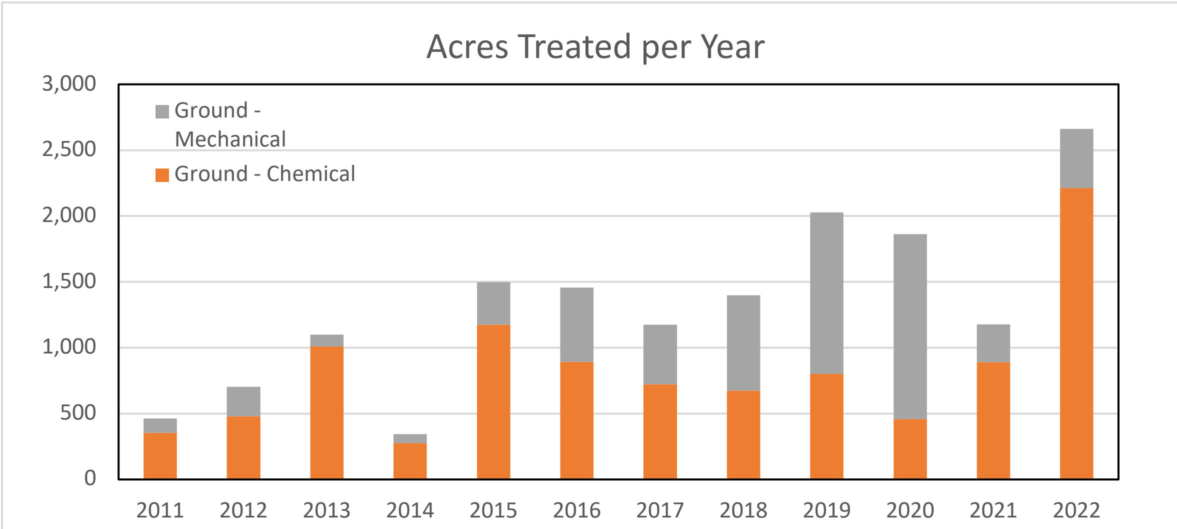


Figure 9. Area of ground treatments (manual/mechanical and chemical) on flammable invasive species (buffelgrass, fountain grass, tickgrass, Sahara mustard, Natal grass, salt cedar, and stinknet) done by park staff, intern field crews, and volunteers, 2011-2022. Aerial spraying acreage is shown separately in Figure 10.

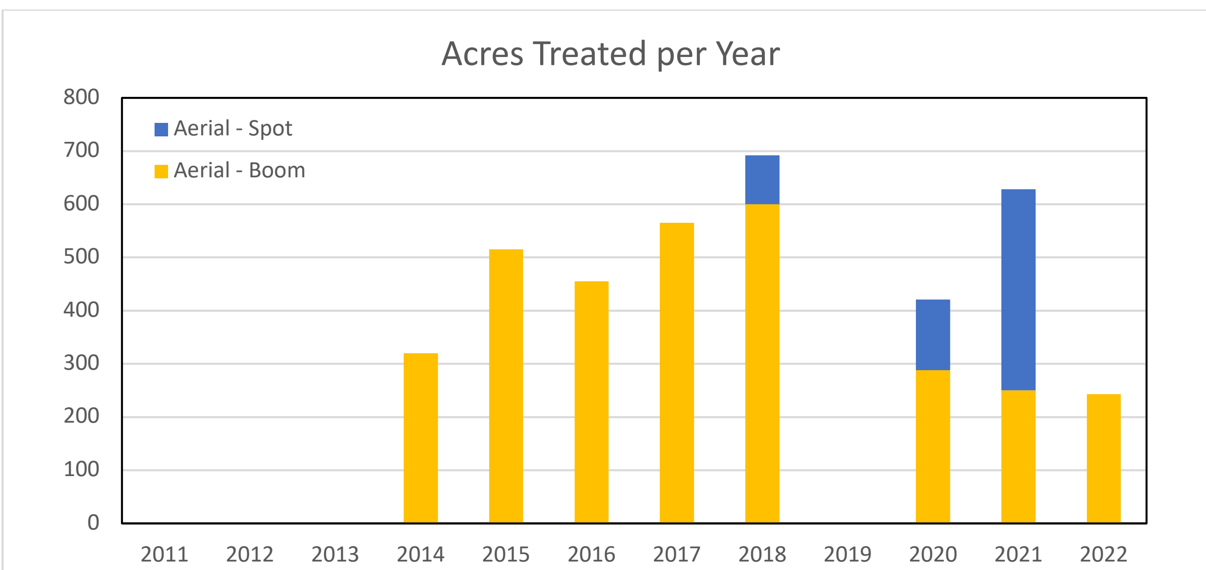


Figure 10. Acres of buffelgrass aerially treated by the helicopter boom and spot-sprayers. Due to dry conditions in the summer of 2019, aerial spraying was delayed until October, 2019 (FY20). It was too dry in CY20 to perform any aerial spraying during the monsoon of 2020.

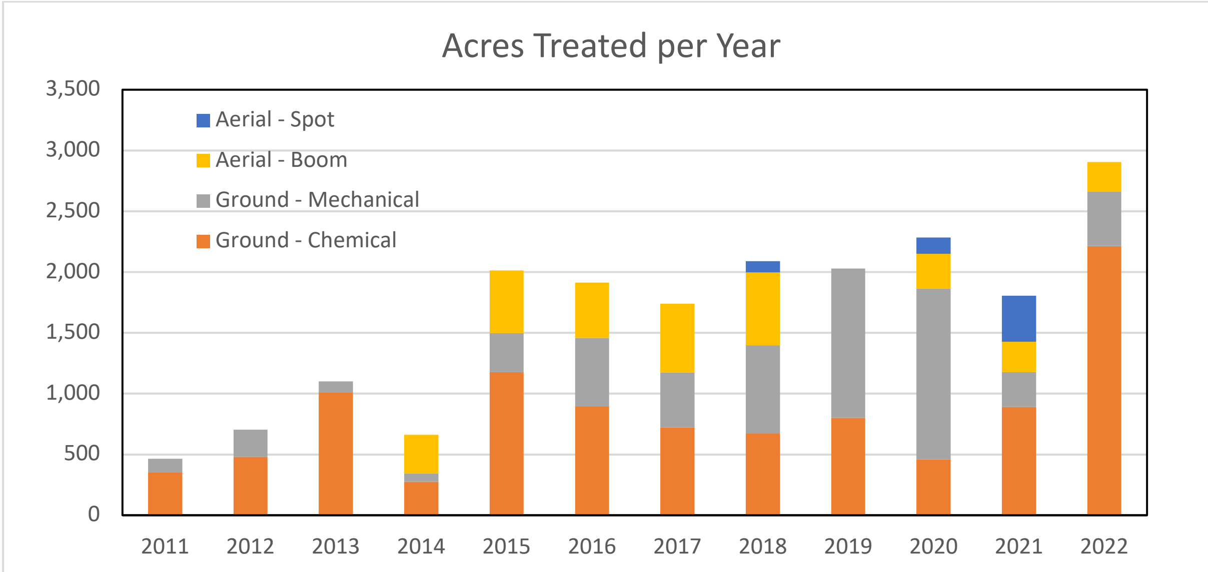


Figure 10. Total acres of hazard fuel species (mainly buffelgrass) treated by fiscal year by all methods (2011-2022).

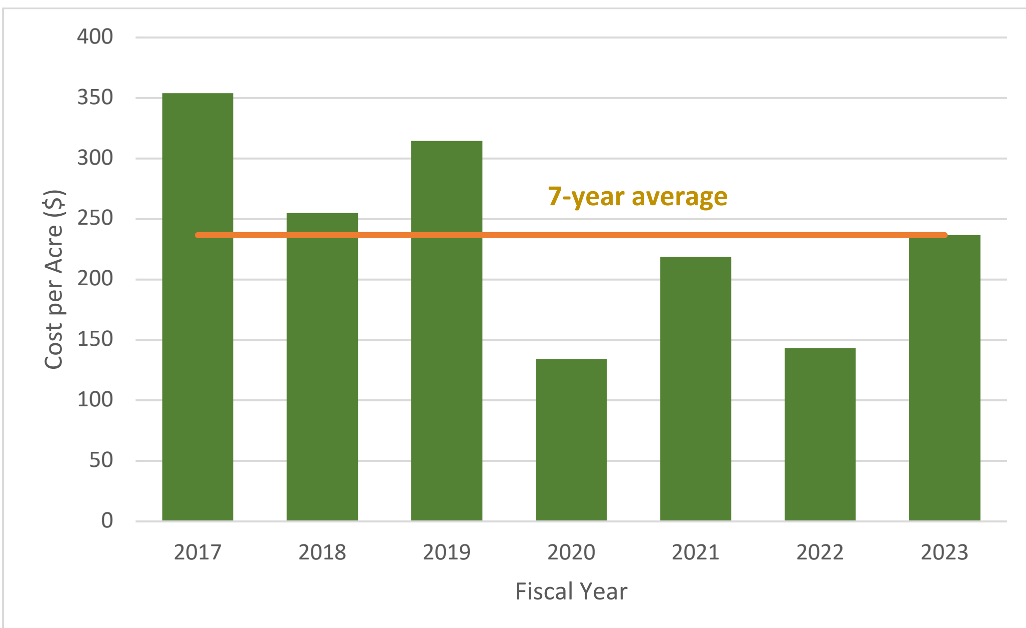


Figure 11. Total costs per treatment acre of invasive plants in the park per acre of hazardous fuels treated over the last seven years. Invasives that do not contribute to hazardous fuel loading make up an insignificant amount of work performed. (Those species include those such as Siberian elm, sow thistle, horehound, and tree tobacco.) The average for the latest seven years is $237/acre.

5. Success Stories

Over the past 10 years, the park's resource managers have achieved significant successes in buffelgrass control in large parts of the park, with a focus on protecting cultural resources, sensitive wildlife habitat, high visitor-use areas, and WUI areas. One measure of that success is the fact that we are **running out of places to do volunteer group pulls**. As recently as 2007, we had buffelgrass pulls directly adjacent to the tour loop of the Rincon Mountain District (RMD). We now are struggling to find patches that our volunteers can hike to, because they sometimes show up wearing tennis shoes. (We do still have huge areas of buffelgrass in very remote areas.)

Another example is the **Freeman Homestead** area of RMD (Figure 12) where 12 acres of a dense buffelgrass infestation were treated using volunteer group buffelgrass pull events from 2007 to 2012, and seedlings were killed by staff following up with herbicide. Native plant species reappeared from the seed bank or from seed from adjacent areas, and the site is now considered to be restored with infrequent and minimal retreatment efforts needed.

Figure 12. **Freeman Homestead** area in September, 2007 (left), and in March 2012 (right).

At **Sus Hill** (Figures 13, 14), a 47-acre infestation received mostly ground chemical treatments from 2012-2018, resulting in near eradication of buffelgrass, and putting it in a condition where manual removal during cooler winter months can maintain it. It is prime for “adoption” by volunteers.

Figure 13. Staff spraying buffelgrass on **Sus Hill** with herbicide, monsoon, 2014.

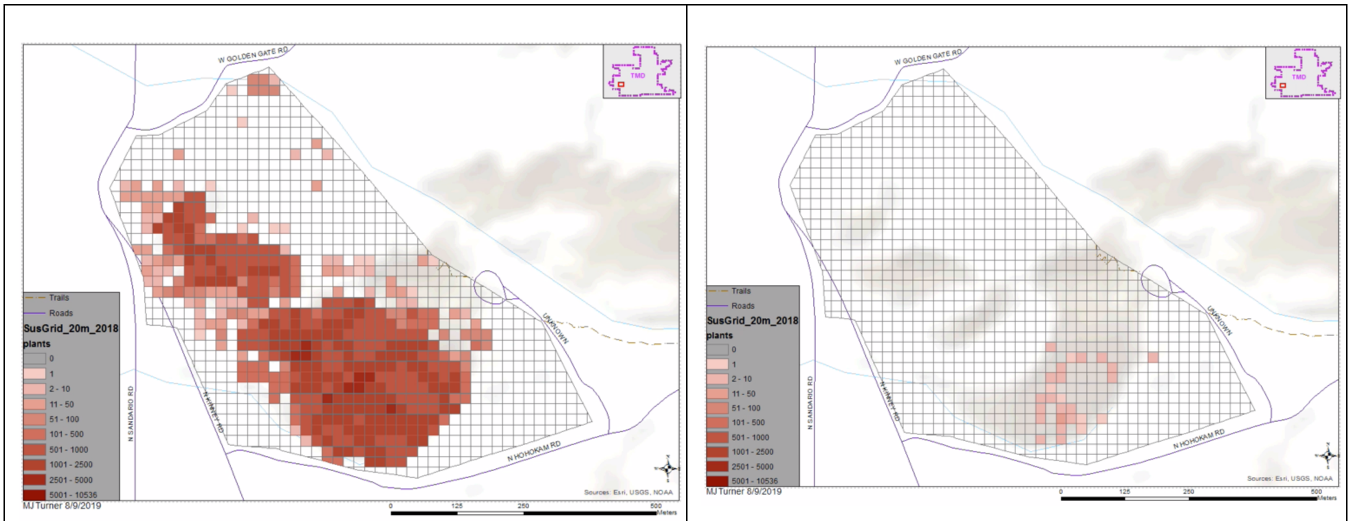


Figure 14. Analysis of buffelgrass abundance on **Sus Hill** of TMD. Number of plants in each 20x20m pixel, with darker colors being higher density. First year of full area treatment, 2013 (left), and in 2018 (right).

The area with an early and sustained use of herbicide is **lower Tanque Verde Ridge** (Figure 15). These maps show treated area in the height of operations there and during recent operations. The area is now in a maintenance state and ready to be adopted out to the care of volunteers.

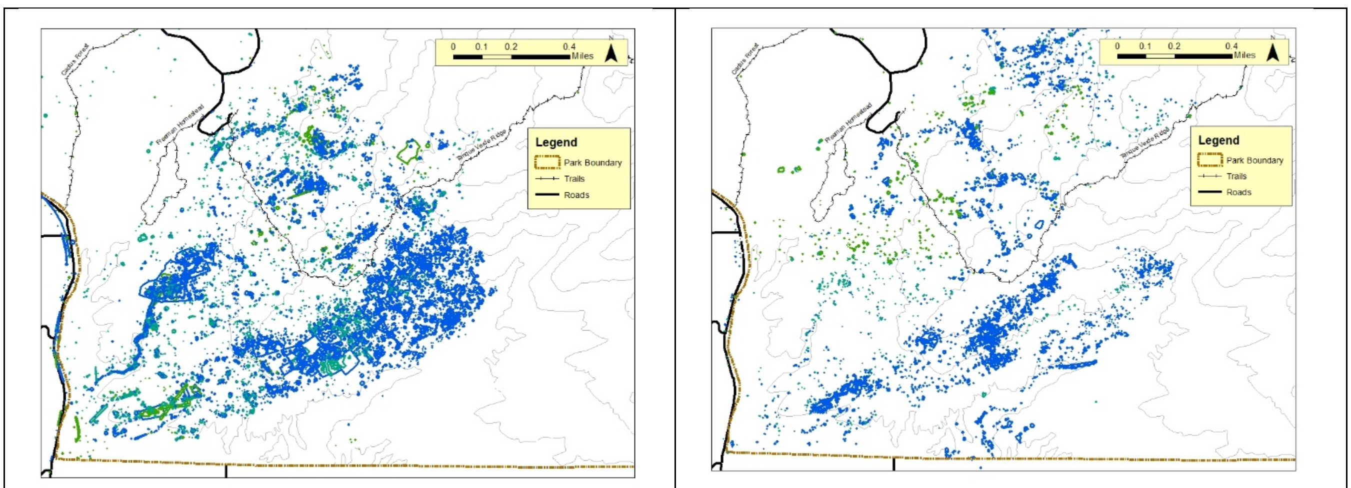
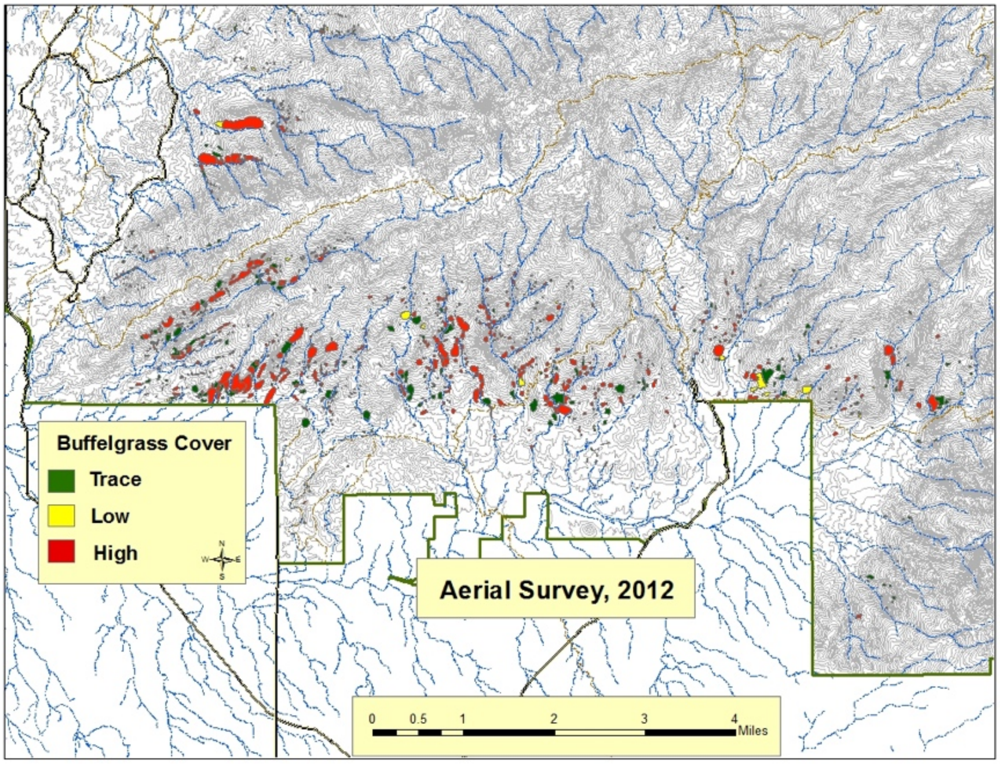
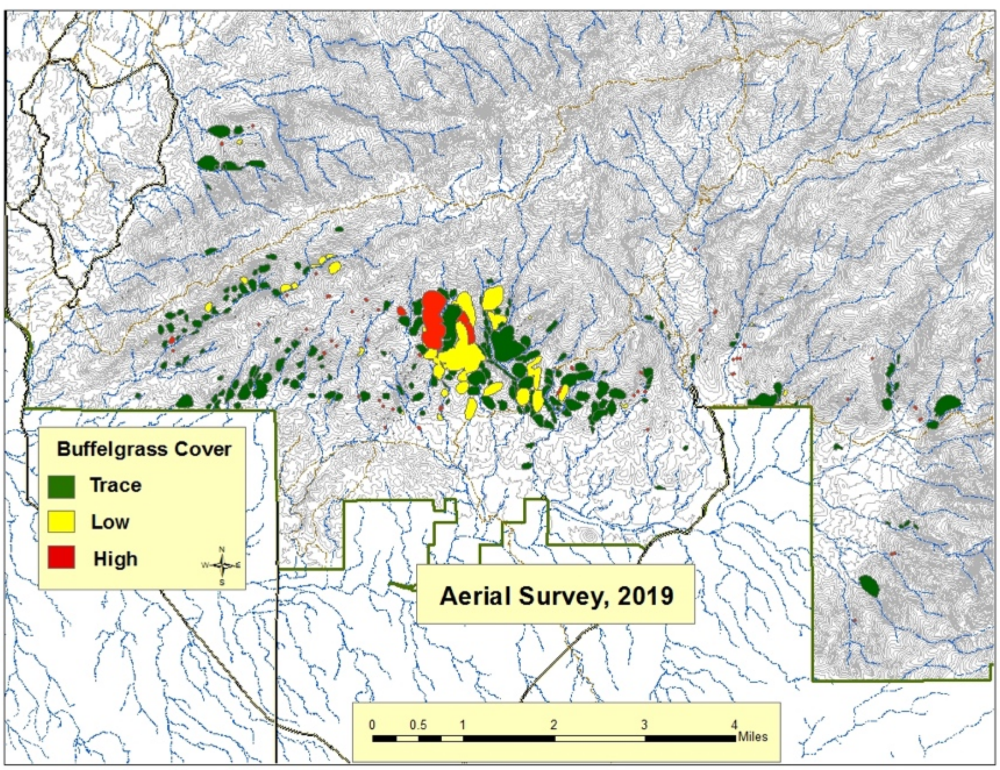


Figure 15. Buffelgrass treatments from **lower Tanque Verde Ridge** in FY2011-FY2013 (left), and FY2017-FY2019 (right). Blue shapes are chemical treatments, and green shapes are mechanical treatments. These maps **includes the part of the Freeman Homestead area** shown in Figure 12.

Results of **aerial mapping** in 2012 and again in 2019 (Figure 16) show the impact that aerial herbicide application has on suppressing buffelgrass. The figure includes the 2012 aerial survey map of RMD, the 2019 survey map, and aerial boom treatments from 2014-2019.

2012 Aerial survey results. Numerous patches of dense buffelgrass across the south aspects of RMD.	
2019 Aerial survey results. Most patches have persisted, and there are more patches, but very few high density patches.	

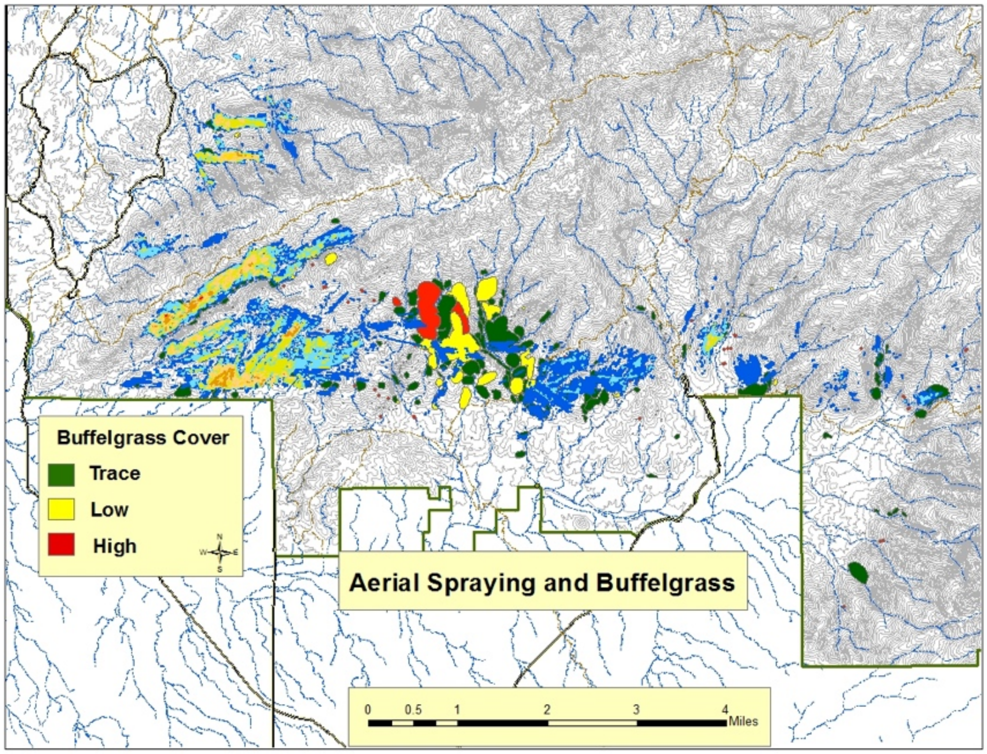
Aerial boom spraying locations overlaying the 2019 aerial survey map. The warmer the color of the sprayed areas, the more years it has been treated. The area that has not been aerially treated (and not treated on the ground because of the remoteness and ruggedness) has greatly increased in buffelgrass coverage, including a very large monoculture of buffelgrass.	

Figure 16. Effects of aerially boom-spraying buffelgrass in RMD. Buffelgrass is suppressed where sprayed, but has exploded where not sprayed, creating a huge and expanding fire risk.

6. Summary

The park has been successful in suppressing buffelgrass and other invasive species in areas that it has been able to treat. Follow-up treatments to guarantee long-term success have not been found for the most remote areas.

During the record-breaking wet monsoon of 2021 and wet August of 2022, warm season invasive grasses boomed. Germination and survival of buffelgrass, fountaingrass, and especially tickgrass increased drastically.

The fledgling Adopt an Area program and the older Weed Free Trail program have seen an increase in recruitment, with 13 new trainees coming on board in FY22 and FY23. A volunteer coordinator is needed to increase capacity.

In 2023, the park is poised to reevaluate the program and consider new and different tools. A new Restoration Ecologist will also take over as invasive species lead.

Figure 17. Buffelgrass fires plague Tucson's sister city, Hermosillo, Sonora, Mexico. (from a news story about buffelgrass fires, January, 2023)

7. Literature Cited

BWG. 2008. Southern Arizona Buffelgrass Strategic Plan. Buffelgrass Working Group. A. Rogstad editor. 42 p. http://www.buffelgrass.org/content/southern-arizona-buffelgrass-startegic-plan

Esque, T., C. Schwalbe, J.A. Lissow, D.F. Haines, D. Foster, and M.C.Garnett. 2007. Buffelgrass fuel loads in Saguaro National Park, Arizona, increase fire danger and threaten native species. Park Science 24:33-56.

Gornish, E.S., K. Franklin, J. Rowe, and A. Barberán. 2020. Buffelgrass invasion and glyphosate effects on desert soil microbiome communities. Biological Invasions, https://doi.org/10.1007/s10530-020-02268-8.

Hussain, F., I. Ilahi, S. A. Malik, A.A. Dasti, and B. Ahmad. 2011. Allelopathic effects of rain leachates and root exudates of *Cenchrus ciliaris* L. and *Bothriochloa pertusa* (L.) A. Camus. Pakistan Journal of Botany 1: 341-350.

Jarnevich, C.S., C.C. Thomas, N.E. Young, P. Grissom, D. Backer, and L. Frid. 2022. Coupling process-based and empirical models to assess management options to meet conservation goals. Biological Conservation 265.

Marshall, V.M., M.M. Lewis, and B. Ostendorf. 2012. Buffelgrass (Cenchrus ciliaris) as an invader and threat to biodiversity in arid environments: a review. Journal of Arid Environments 78:1-12.

McDonald, C.J., and G.R. McPherson. 2011. Fire behavior characteristics of buffelgrass-fueled fires and native plant community composition in invaded patches. Journal of Arid Environments 75:1147-1154.

McDonald, C.J., and G.R. McPherson. 2013. Creating hotter fires in the Sonoran Desert: buffelgrass produces copious fuels and high fire temperatures. Fire Ecology 9:26-39.

Moody, M.E., and R.N. Mack. 1988. Controlling the spread of plant invasions: the importance of nascent foci. Journal of Applied Ecology 25:1009-1021.

Olsson, A.D., J. Betancourt, M.P. McClaran, and S.E. Marsh. 2012. Sonoran Desert ecosystem transformation by a C_4 grass without the grass/fire cycle. Diversity and Distributions 18:10-21.

Pima County Office of Emergency Management et al. 2013. Pima County Community Wildfire Protection Plan. Logan Simpson Design Inc. Tucson, AZ. 225 p. https://webcms.pima.gov/

Ryan, K.C., A.T. Jones, C.L. Koerner, and K.M. Lee. 2012. Wildland fire in ecosystems: effects of fire on cultural resources and archaeology. USDA Forest Service General Technical Report RMRS-GTR-42-vol. 3. Fort Collins: USDA Forest Service, Rocky Mountain Research Station. https://doi.org/10.2737/RMRS-GTR-42

Wilder, B.T., C.S. Jarnevich, E. Baldwin, J.S. Black, K.A. Franklin, P. Grissom, K.A. Hovanes, A. Olsson, J. Malusa, and A.S.M.G. Kibria. 2021. Grassification and fast-evolving fire connectivity and risk in the Sonoran Desert, United States. Frontiers in Ecology and Evolution, Frontiers Media S.A, 2021, 9, .10.3389/fevo.2021.655561...hal-03426144.

Williams, D.G., and Z. Baruch. 2000. African grass invasion in the Americas: ecosystem consequences and the role of ecophysiology. Biological Invasions 2:123-140.

Appendix A. Research Summary. Invasive species/Hazard Fuels research projects at or involving Saguaro National Park. Projects supported by **Hazard Fuels** and related funding are shown in **bold text**.			
Year	Research Project Title	Investigators	Fund Source
2003	Effects of Desert Wildfires on Desert Tortoise (*Gopherus agassizii*) and Other Small Vertebrates	Todd Esque, Cecil Schwalbe, Lesley DeFalco, Russell Duncan, Timothy Hughes	USGS
2007	Effectiveness of Glyphosate Herbicide on Buffelgrass (*Pennisetum ciliare* L.) at Saguaro National Park, Tucson, Arizona.	Dana Backer, Danielle Foster	NPS Nat. Res. Protection Program
2007	**Impacts on Sonoran Desert Vegetation from Fires in Buffelgrass**	**Christopher McDonald, Guy McPherson**	**Hazard Fuels**
2007	Buffelgrass fuel loads in Saguaro National Park, Arizona, increase fire danger and threaten native species	Todd Esque	USGS
2009	**Herbicide effects on mortality of invasive buffelgrass (*Pennisetum ciliare*) and native Upper Sonoran desert vegetation**	**Travis Bean, Grant Casady, Mitch McClaran**	**Hazard Fuels**
2009	Adaptive Research on Effective Control of Buffelgrass at Saguaro National Park	Dana Backer, Chris Hannum	Western National Parks Association
2009	**Assessment and Guidelines for Determining Effectiveness and Longevity of Buffelgrass Treatments in Southern Arizona**	**Molly Hunter**	**Hazard Fuels**
2009	Adaptive Research on Effective Control of Buffelgrass at Saguaro National Park	Dana Backer, Chris Hannum	Western National Parks Assn.
2011	Restore Native Saguaro Community Following Removal of Invasives – A Pilot Study	S. Woods, J. Fehmi	Desert Southwest CESU, National Park Service
2011	**Predicting buffelgrass greenup to improve fuels treatment efficacy**	**Steven Smith, Travis Bean**	**Hazard Fuels**
2012	Ecological Characteristics of Sites Invaded by Buffelgrass (*Pennisetum ciliare*)	Scott Abella, Lindsay P. Chiquoine	NPS Nat. Res. Preservation Proj.
2013	Soil, Vegetation, and Seed Bank of a Sonoran Desert Ecosystem Along an Exotic Plant (*Pennisetum ciliare*) Treatment Gradient	Scott Abella, Lindsay P. Chiquoine	NPS Nat. Res. Preservation Proj.

2014	**Hydrological Impacts of Buffelgrass on Wildfires**	**Jon Pelletier, Tyson Swetnam**	**Hazard Fuels**
2016	Mapping Presence and Predicting Phenological Status of Invasive Buffelgrass in Southern Arizona Using MODIS, Climate and Citizen Science Observation Data	Cynthia Susan Wallace, Jessica Walker, Susan Skirvin, Caroline Patrick-Birdwell, Jake Weltzin, Helen Raichle	USGS Land Change Science, Land Remote Sensing and National Park Monitoring Project
2017	Occurrence, Fate, and Transport of Aerially Applied Herbicides to Control Invasive Buffelgrass within Saguaro National Park Rincon Mountain District, Arizona, 2015–18	Nicholas Paretti, Kimberly Beisner, Bruce Gungle, Michael Meyer, Bethany Kunz, Edyth Hermosillo, Jay Cederberg, and Justine Mayo	USGS
2018	Forecasting an invasive species' distribution with global distribution data, local data, and physiological information	Catherine Jarnevich, Nicholas Young, Marian Talbert, Colin Talbert	NPS Nat. Res. Preservation Proj. and USGS Invasive Species Program
2019	**Invasive buffelgrass detection using high-resolution satellite and UAV imagery on Google Earth Engine**	**Kaitlyn Elkind, Temuulen Sankey , Seth Munson, Clare Aslan**	**DOI Wildland Fire Resilient Landscape Prog.**
2019	Developing an expert elicited simulation model to evaluate invasive species and fire management alternatives	Catherine Jarnevich, Catherine Cullinane Thomas, Nicholas Young, Sarah Cline, Leonardo Frid	NPS Nat. Res. Preservation Proj. and USGS Invasive Species Program
2019	**Assaying phytotoxicological selectivity of radicinin, a potential *Cenchrus ciliaris* bioherbicide on native Arizona Upland-Sonoran Desert flora**	**Kim Franklin**	**Hazard Fuels**
2020	Assessing ecological uncertainty and simulation model sensitivity to evaluate an invasive plant species' potential impacts to the landscape	Catherine Jarnevich, Nicholas Young, Catherine Cullinane Thomas, Leonardo Frid	NPS Nat. Res. Preservation Proj. and USGS Invasive Species Program
2020	Buffelgrass invasion and glyphosate effects on desert soil microbiome communities	Elise Gornish . Kim Franklin . Julia Rowe . Albert Barbera	University of Arizona
2020	Effectiveness of a decade of treatments to reduce invasive buffelgrass (*Pennisetum ciliare*)	Max Li Yue, Seth Munson, Ya-Ching Lin	USGS Invasive Species Program
2022	Coupling process-based and empirical models to assess management options to meet conservation goals	Catherine Jarnevich, Catherine Cullinane Thomas, Nicholas Young, Leonardo Frid	NPS Nat. Res. Preservation Proj. and USGS Invasive Species Program

2022 ongoing	Population dynamics of buffelgrass (*Pennisetum ciliare*), an invasive perennial bunchgrass in the Sonoran Desert	Katherine Hovanes	University of Arizona