University of Arizona - GIST 909 Capstone

Using Earth Observations to Map the Spatial Distribution of Buffelgrass in the Sonoran Desert

Masters Report

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1. Abstract

The Sonoran Desert is recognized as an arid ecosystem with a year-round warm climate and biodiverse desert flora. The desert spans across the southwestern United States and northwestern Mexico. Much of the native flora, like the saguaro cactus (*Carnegiea gigantea)*, are important members of the Sonoran Desert for native wildlife and human society. Currently, the ecosystem is being threatened by the rapid spread of an invasive grass species known as buffelgrass (*Cenchrus ciliaris*), as it is changing the desert landscape to a grassland and contributes to more flammable fuel of surging wildfires. This project, in partnership with the Tucson Sonoran Desert Museum's "Save our Saguaros" initiative, utilized satellite imagery of Tumamoc Hill and Sentinel Peak from Google Earth to develop and assess an optimal workflow marking the spatial distribution of buffelgrass via manual mapping. This would aid in early detection and rapid response management not only within the study area but other areas of the Sonoran Desert. GIS analysts worked with a predetermined buffelgrass identification key to manually plot growth sites of the species across the study site. Satellite Imagery from 2016-2020 was found to provide the best visual reference for historical buffelgrass growth and through remote mapping and ground truthing a significant accuracy level was achieved.

Key Terms
Sonoran Desert, buffelgrass, conservation, wildfires

2. Ethics Statement

In conducting this study, we acknowledge that we have an obligation to society, our colleagues, and the profession, and to the individuals in our society to deliver the best possible quality of work with honesty and integrity. We strive to contribute to the community to the extent possible, feasible, and advisable so we may meet our obligation. We strive to respect the work and data we have utilized for our study and of others and intend to contribute to the discipline to the extent possible to meet our obligation to our colleagues and the profession. We strive to show respect for copyright and intellectual property rights to authors of any material we obtained to produce our data. We strive to respect privacy and be honest to meet our obligations to the individuals in society. We understand that through geospatial or data manipulations we have the obligation to be sensitive as some displays of data may be of concern to individuals in our society. We strive to make our data widely available and communicate our findings to contribute to the betterment of our society. We looked to the University of Arizona's GIS Institute Code of Ethics for guidance on conducting our study and upholding the standard of the University's ethical principles.

In conducting our study, we were guided in all professional activities by the highest standards of the University of Arizona and the Sonoran Desert Museum. We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and indigenous communities through education offerings, partnerships, and community service. This project was performed in collaboration with fellow MS-GIST student, Victor Batres/Scarlet Jackson, as directed and approved by the university GIST program director, Chris Lukinbeal. Our supervisors seeked to provide opportunities of professional development and advancement of persons working on the study to meet obligations for the betterment of the profession. We have included clear details to the intent of the study and the proper potential use of the data and methodology to meet our obligations to our society and the profession. Equity was promoted and inclusion of persons without regard to race, religion, gender, disability, age, national origin, political affiliation, sexual orientation, gender identity, or gender expression was practiced to fulfill our obligations to individuals and our society.

3. Introduction

3.1 Background Information

Invasive plant species are those that have been introduced to an ecosystem where they did not historically evolve and outcompete the native flora to often decrease biodiversity within the ecosystem (Olsson *et al.*, 2012). Invasive grasses can be particularly damaging to not only the biodiversity of native flora, but to the entire ecosystem, as they may lower species richness, increase fire fuel, and change fire regimes (D'Antonio, C.M. & Vitousek, P.M., 1992). Specifically, African bunch grasses can have significant effects on size distribution of columnar cacti and could even drive local extinction in some cases (Morales-Moreno, D. & Molina-Freaner, F., 2008).

Buffelgrass (*Cenchrus ciliaris)* is a bunchgrass native to Africa, Asia, and the Middle East, and is classified as an invasive noxious weed in the Sonoran Desert of Arizona (Olsson *et al.*, 2011) (NPS, 2019). Buffelgrass is highly drought tolerant and has a high seed production rate. It was brought to the U.S. starting in the 1930's by the U.S. Soil Conservation Service to aid with soil erosion and for livestock foraging (NPS, 2019). Since then, it has spread into unwanted areas of the U.S. Southwest as it thrives in arid conditions.

Early detection and rapid response is the most effective way to control invasive infestations while their distribution is not yet widely established. Being able to map buffelgrass can aid land managers in the first steps of controlling the infestation. Currently, there is no methodology to map buffelgrass that can be easily replicated. The goal of this study is to understand the feasibility of mapping buffelgrass aerially, and if achievable, distribute the steps to follow this methodology to land managers battling the invasive species.

3.1.1 Study Area and Period

The study area is composed of two nature preserves: Sentinel Peak ("A" Mountain) and Tumamoc Hill located in Tucson, Arizona (Fig. 1). They are located east of the Tucson Mountains and west of the Tucson urban center. Both sites present an ideal capsule of the Northern Sonoran Desert given the abundance in staple native desert flora such as the saguaro cactus (*Carnegiea gigantea*), blue palo verde (*Parkinsonia florida*), ocotillo (*Fouquieria splendens*), and jumping cholla (*Cylindropuntia fulgida*) (Arizona-Sonoran Desert Museum, 2015). The study area also holds an abundance in the project's subject of interest, buffelgrass (*Cenchrus ciliaris*). The average elevation of the study area is 2,800 ft (Arizona-Sonoran Desert Museum, 2015). As of 2021, the average precipitation is 10.61 in. and primarily occurs during the mid to late summers (July-September) (National Weather Service).

The study took place primarily through the months of June and July of 2022, which is when buffelgrass is most commonly observed in its golden-straw tone. This comes from the early summer climate as buffelgrass is generally dry in constitution. The satellite and aerial images utilized throughout the study are from Google Earth Pro. The reference layers are WGS 1984 satellite images with various spatial resolutions, depending on the visualized subject matter. Initial research has previously been conducted in this study area by the Sonoran Desert Museum (SDM). Metadata and incorporated images developed by the SDM partners are included in the workflow. Using a 250 m. grid overlaid on the study area of this project, 13 grid cells were mapped by the Arizona-Sonora Desert Museum Standard mapper and by the individual mappers included in the project. The 13 grid cells highlighted in Figure 2 were used to produce results and analysis of contingency tables.

Figure 1. The project study area focuses on Tumamoc Hill and Sentinel Peak ("A" Mountain).

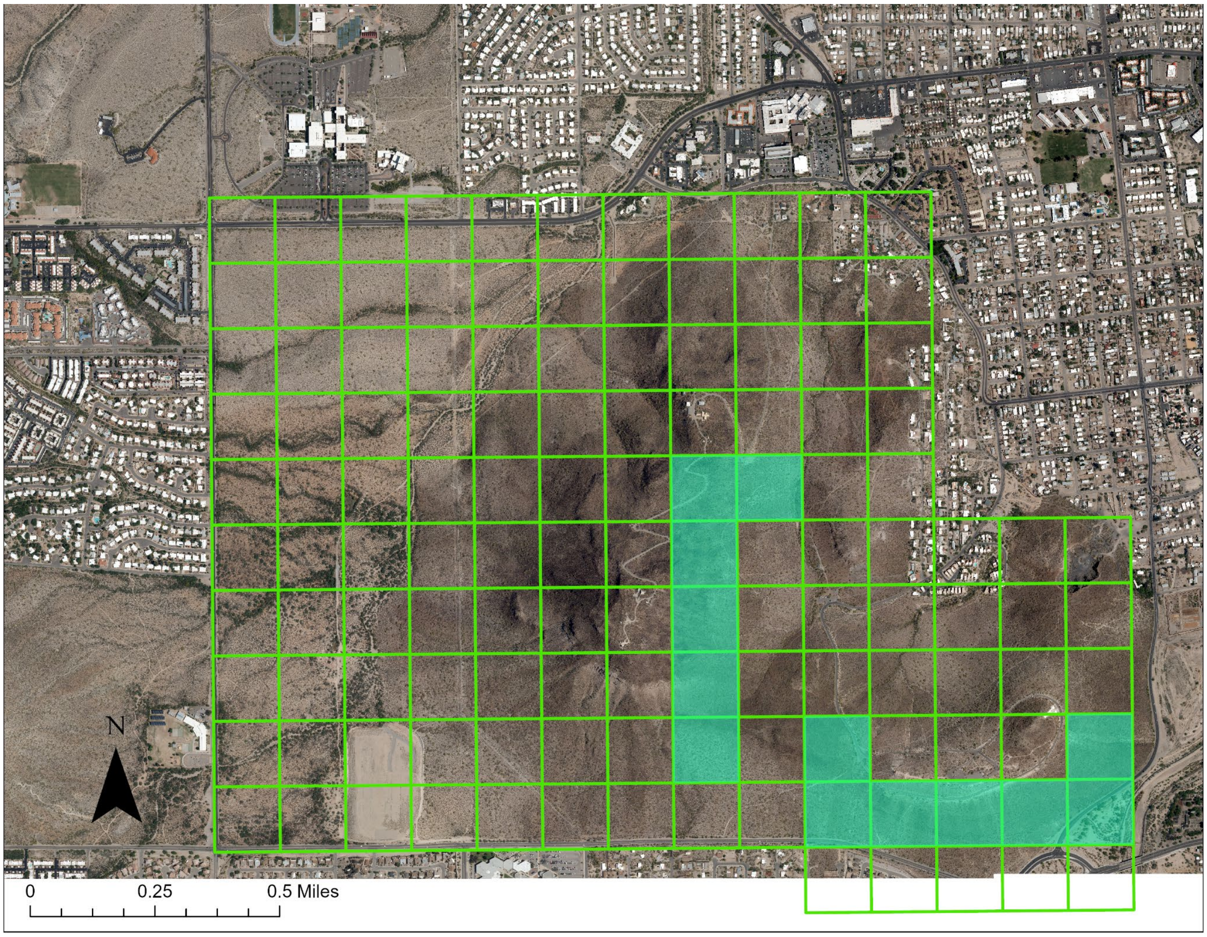

Figure 2. The grid cells highlighted are those that were mapped by all members in the project and were used for results and analysis.

3.2 Project Partners & Objectives

We partnered with the Save our Saguaros non-profit organization of the Arizona-Sonora Desert Museum. The mission of the Arizona-Sonora Desert Museum (ASDM) is to inspire people to live in harmony with the natural world by fostering love, appreciation, and understanding of the Sonoran Desert. The museum was founded in 1952 and is now ranked as one of the top 10 museums in the country on TripAdvisor.com. Save our Saguaros is a non-profit organization run by the Arizona-Sonora Desert Museum to help conserve the invaded desert of Tucson. The Save our Saguaros organization hosts buffelgrass pulls and asks for volunteer community mapping of the invasive species to help maintain the spread.

4. Methodology

4.1 Proposed Methodology and Assessing Feasibility

Mapping buffelgrass is difficult, and usually hard to repeat the methodology. The main goal of this project is understanding the feasibility of mapping buffelgrass and seeing if it is possible to create a repeatable early detection rapid response methodology. We began with a criteria key provided by the Sonora Desert Museum. There are justifications to the criteria we are using as a key to map buffelgrass (Table 1.). Buffelgrass bunches have a distinct texture when viewed from aerial imagery. It is usually a pebbled texture in continuous swaths. The color of buffelgrass when easiest to detect is a golden straw-like tone. This is different from many native grasses in the area, which are usually a lighter color. Per the ASDM key (Table 1), the size of a buffelgrass plant is typically <1m in diameter across. The size of an infestation is usually large, typically >100m across. Buffelgrass also rarely grows on north-facing slopes. For these reasons we have chosen for the key criteria to include texture, color, plant size, infestation size, and aspect.

Table 1. Proposed Methodology for Mapping Dormant Buffelgrass (*Cenchrus ciliaris*) in the Sonoran Desert from Aerial Orthoimagery

	Criteria	Description	Points
1	**Texture**	Buffelgrass bunches have a distinct uniform pebbled texture. The grass tends to present in contiguous swaths with an orange skin or cottage cheese appearance (see sample images).	3
2	**Color**	Straw-like color with golden tones. Many native grasses will tend to present in a lighter, whiter color.	1
3	**Size of plant**	Other species like brittlebush (*Encelia farinose*) will also present in a pebbled pattern, but each individual bush will be >1m in diameter while buffelgrass is almost always <1m in diameter across.	1
4	**Size of infestation**	If the infestation is >100m across, it will be more likely to be buffelgrass. Few other things take over large swaths of land in the same way.	1
5	**Aspect**	Buffelgrass rarely grows on the north face of a slope. If what you see is on the south, west or east facing slope, it has a higher chance of being buffelgrass	1
	TOTAL	• We consider something to be buffelgrass if it totals 5 or more points • A total of 4 points is a maybe	

4.2 Individual Mapping

Multiple geographic information system (GIS) analysts used the 250m grid that was overlaid on Google Earth Imagery of Tumamoc Hill and “A” Mountain to map buffelgrass presence polygons (Fig. 3). Analysts viewed the imagery from directly above the ground at a perpendicular angle, used the predetermined key to ocularly identify buffelgrass, and traced polygons around the infestation boundaries. It took each mapper about one to three hours to map a grid cell, depending on its complexity. When analysts completed mapping buffelgrass infestations each week the outcomes were compared. Any areas of discordance in a given polygon were reviewed by another experienced analyst. Adjustments and calibrations took place each week to create the most efficient first steps in the early detection rapid response methodology for mapping buffelgrass infestations.

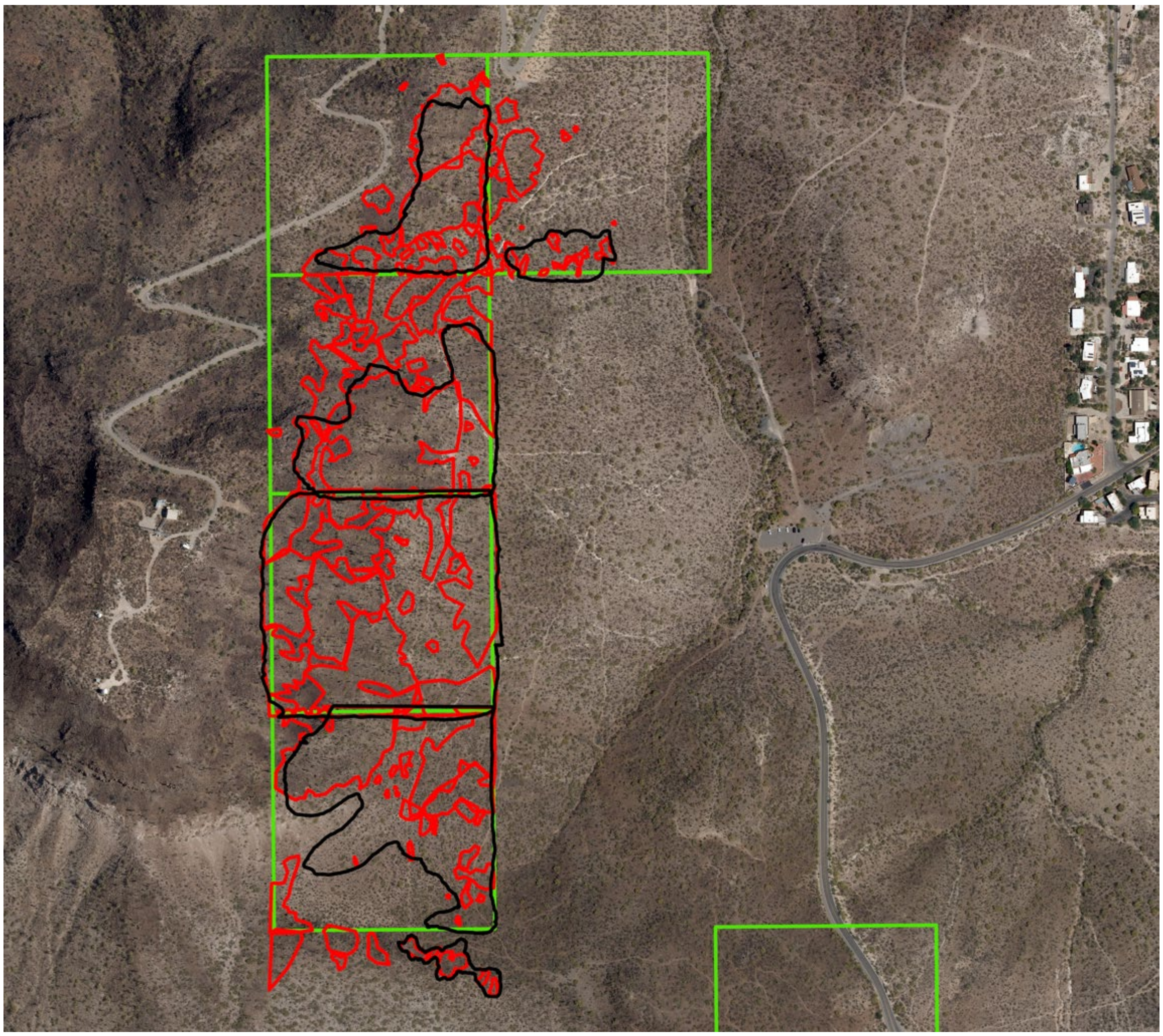

Figure 3. Example of Standard mapper polygons (in red) overlaid with individual mapper polygons (in black).

4.3 Assessing Methodology Accuracy

The team used contingency tables to compare the variation and accuracy of each mapper. For comparison, we used the polygons mapped from an experienced member of the Arizona-Sonora Desert Museum (ASDM Standard). This mapper was selected as the "key" while all other mappers were compared to this standard.

Table 2. Contingency Table Equations

		ASDM Standard		
		Buffelgrass	*No buffelgrass*	***Mapper Total***
Mapper	*Buffelgrass*	True Positives	False Positives	TP + FP
	No Buffelgrass	False Negatives	True Negatives	FN + TN
	Standard Total	TP + FN	FP + TN	***Total***

Mapper's Accuracy $\frac{TP}{TP+FP}$

Overall Accuracy $\frac{TP+TN}{TP+TN+FP+FN}$

5. Results

5.1 Contingency Agreement Table

Results were captured using contingency analysis tables. Polygons of individual mappers were compared to that of the Arizona-Sonora Desert Museum Standard (ASDM Standard). Equations for how these totals were calculated can be found in Table 2[LC(1)] . Areas within the mapped boundaries where a mapper agreed with the ASDM standard regarding the presence of buffelgrass were identified as True Positives (TP). If a mapper identified buffelgrass where the standard did not, False Positives (FP) were marked accordingly. Conversely, areas lacking the presence of buffelgrass where the standard identified its presence were marked as False Negatives (FN). Lastly, areas where buffelgrass was not identified by both parties were identified as True Negatives (TN). Given the analysis matrix and its parameters, 1) mapper accuracy for presence of buffelgrass and 2) overall accuracy of mapper's data agreement to the ASDM standard could be calculated per individual. The ASDM Standard was mapped by an experienced buffelgrass expert from the Sonora-Desert Museum. Table 3 shows the results of Victor's and Scarlet's mapping compared to the standard. Victor had a mapper accuracy of 86% and an overall accuracy of 79%. Scarlet had a mapping accuracy of 73% and an overall accuracy of 74%.

Table 3. Participants Polygons Compared to the Arizona-Sonora Desert Museum Standard (ASDM Standard).

		ASDM Standard		
Victor		*Buffelgrass*	*No Buffelgrass*	***Total (sq ft)***
	Buffelgrass	**1,832,659**	**307,557**	**2,140,216**
	No Buffelgrass	**664,121**	**1,718,037**	**2,382,158**
	Total (sq ft)	**2,496,780**	**2,025,594**	**4,522,374**

Mapper Accuracy	**86%**
Overall Accuracy	**79%**

		ASDM Standard		
Scarlet		*Buffelgrass*	*No Buffelgrass*	***Total (sq ft)***
	Buffelgrass	**2,034,181**	**742,478**	**2,776,659**
	No Buffelgrass	**366,031**	**1,082,615**	**1,448,646**
	Total (sq ft)	**2,400,211**	**1,825,094**	**4,225,305**

Mapper Accuracy	**73%**
Overall Accuracy	**74%**

6. Conclusions

6.1 Discussion

Buffelgrass is an Africa bunch grass, and has invaded many parts of the arid land of the Southwest U.S. When dormant, buffelgrass creates mass fuel for wildfires acting as a catalyst for destruction. Mass amounts of fuel in a typically barren landscape can have major effects on the ecosystem and create fire regime shifts. Columnar cacti, like the beloved Saguaro cactus, can be largely affected by these fires, as studies have shown average diameter decreases of columnar cacti in these ecosystems experiencing fire regime shifts due to bunch grasses. Being able to control the spread of these invasive species can allow land managers to protect these ecosystems and conserve some of the native flora that is left. The methodology workflow assessed in this project could act as some of the first steps in creating an early detection rapid response methodology to get ahead of the spread of this invasive species.

The overall accuracy for the mappers during this project fell between 74 and 79 percent. This means that there is a 74-79% chance that the presence polygons mapped for buffelgrass will contain buffelgrass when surveyed in the field. This also means that there is a 74-79% chance that buffelgrass will be absent in areas where buffelgrass is not mapped. Depending on the specificity needed for a land management team, we feel that these accuracy results deem this methodology a reliable first step in creating an early detection rapid response plan for buffelgrass in the Sonoran Desert.

The team feels that the methodology was efficient and effective. It took roughly one to three hours for a mapper to map an individual grid cell, depending on the complexity of the landscape and characteristics. We disclaim that the only buffelgrass mapped was dormant, as it is more visually recognizable than its other life stages. Additionally, we only used Google Earth Images from 2016 to 2019. Another thing to consider when repeating this methodology is that accuracy may depend on the mapping style of the individuals involved in the project. Some may take a more detailed approach to mapping, while others may be more generalized. Either way can be effective depending on the goals of the land manager. We also disclaim that this methodology should be revised to meet a more specified criteria if the species of concern is something other than buffelgrass. Similarly, if the study area is anywhere outside of Southern Arizona, methodology may need to be revised.

6.2 Future Work

Buffelgrass is an ecological concern on “A” Mountain and Tumamoc Hill, where we were able to map its presence for our project. However, there are hopes for this methodology to be automated and repeatable, so that buffelgrass can be mapped wherever it is established within Southern Arizona. A main area of concern is the Catalina Foothills, also in Tucson, AZ, where saguaro cactus seedling populations are declining due to the buffelgrass infestation (Franklin, 2016). With the help of an automated and repeatable methodology, we hope that this process could aid land managers in the fight against the invasive species.

In future work, we hope that scripts can be developed to find automation in identifying buffelgrass within the study area. Eight grid cells were utilized for contingency tables. This project would have more compelling data if more individuals were involved in mapping buffelgrass, and more land was covered to compare buffelgrass identification. We are hopeful that this project can be continued by future GIST students in collaboration with the Arizona-Sonora Desert Museum.

7. Acknowledgments

This work was made possible by our mentors: Chris Lukinbeal, PhD (University of Arizona, GIST Director), Aaryn Olsson, PhD (University of Arizona), Kim Franklin (Arizona-Sonora Desert Museum), and Ya-Ching Li, MS (Arizona-Sonora Desert Museum).

The team would like to thank our project partner, Save our Saguaros non-profit of the Arizona-Sonora Desert Museum.

Per guidance and approval by Chris Lukinbeal, this MS-GIST 909 project was performed in collaboration with fellow MS-GIST colleague, Victor Batres.

We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and indigenous communities through education offerings, partnerships, and community service.

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