BUFFELGRASS EXPANSION RATE AND DISPERSAL TYPE ON RECENTLY INVADED BARRY M. GOLDWATER RANGE OF SOUTHWESTERN ARIZONA

by

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STATEMENT BY AUTHOR

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Table of Contents

List of Figures

Abstract

Land managers have struggled to develop successful control strategies to address buffelgrass invasion in the Sonoran Desert. Two important variables for control strategies are dispersal type and patch expansion rate (i.e. satellite or invasion front). We investigated these variables along a highway invaded within the last 10 years located south of Gila Bend, Arizona, USA.. Dispersal type was calculated by documenting the location of each buffelgrass individual along a 16 km stretch of highway and using an average nearest neighbor analysis in ArcMap 10.2.2. Thirty-six patches were monitored for four years along a 56 km stretch of highway 85 by documenting the outlines of each patch. Dispersal type registered as satellite dispersal (i.e. clustered on the Nearest Neighbor test), z-score = -47.2, $p < 0.01$. Patch expansion exhibited a median doubling time of 0.81 years. The results of the dispersal type analysis represent an opportunity to enhance control strategies, by targeting buffelgrass satellites and theoretically reducing patch expansion exponentially. The patch expansion rates for buffelgrass were faster than found in past research, giving land managers a clearer understanding buffelgrass patch expansion behavior.

Introduction

Buffelgrass (*Pennisetum ciliare*), a C_4 perennial grass from Africa (Cox et al., 1988), has caused landscape change and been the target for removal in semi-arid regions of southwestern United States (as reviewed in Rogstad, 2008 and Lyons et al., 2013). Buffelgrass success is due in part to its seed dispersal ability (Ernst et al., 1992), high drought tolerance, low water requirements for germination (Ward et al., 2006), and quick uptake of water from dormancy (Reynolds et al., 2004). Fire introduction, however, is the main long-term competitive advantage of buffelgrass in the Sonoran Desert (McDonald and McPherson, 2011). Buffelgrass has been shown to decrease species diversity and native plant cover, indicating that buffelgrass invasion could result in grassland conversion in the long-term (Olsson et al., 2012; Lyons et al., 2013).

Such impacts have made buffelgrass a focus of science and land management in the Sonoran Desert (Rogstad, 2008; Büyüktahtakin et al., 2014). While hand pulling and spraying can successfully remove buffelgrass patches (e.g. Jernigan et al., in press), land managers have struggled to develop successful, long-term control strategies for large areas (Rogstad, 2008). Risk of reinvasion remains the most significant difficulty of controlling an invasive plant (Lookingbill et al., 2014). Sebert-Cuvillier et al. (2010) and Lookingbill et al. (2014), in developing their respective models for reinvasion risk of invasive plants, identified input variables of seed behavior (seed bank persistence, propagule pressure, reproduction, and dispersal pattern), land disturbance, and habitat suitability. Buffelgrass reinvasion, in particular, has been linked to propagule pressure, seed dispersal radius, and seed bank persistence (Winkworth, 1971; Fensham et al., 2013). After a local buffelgrass patch is removed, land managers must continue managing for seedling emergence from the seed bank for 3-4 years and recruitment from regional sources as long as the regional sources remain.

Dispersal pattern has been identified as a particularly important characteristic of invasion (Sebert-Cuvillier et al., 2010; Lookingbill et al., 2014) and, as shown by Moody and Mack (1988) and Cannas et al. (2006), influences not just reinvasion risk, but can lead to exponentially different growth rates. There are two primary, detectible dispersal patterns: (1) invasion along the edge of existing patches (i.e. an “invasion front”, whereby new plants spawn mostly along the edges of the source population) and (2) establishment of satellite populations (i.e. “satellite dispersal”, whereby new plants spawn near and far from the source population, resulting in satellite populations that become new source populations and lead to exponentially greater patch growth rates than invasion front dispersal in models) (Shigesada and Kawasaki, 1997). If an invasion front is the primary means of invasion, then a control strategy of encircling invaded patches would be efficient and risk of reinvasion from distant source patches would be lower (Cannas et al., 2006). Conversely, if invasion by satellite happens, then targeted removal of nascent satellites (e.g. Moody and Mack, 1988) may best slow or stop the invasion, but land managers would need to consider the area’s proximity to source patches when targeting satellites to account for risk of reinvasion (Sebert-Cuvillier et al., 2010; Lookingbill et al., 2014).

It is noteworthy that invasive species can exhibit both invasion front and satellite dispersal patterns (Wilson and Lee, 1989; Cannas et al., 2006). Buffelgrass, specifically, is known to convert ecosystems into grassland (Lyons et al., 2013) (i.e. a large, unbroken patch resembling an invasion front), but its dispersal pattern during invasion remains unestablished in literature. If buffelgrass invades via satellite dispersal, land managers may be able to optimize their control strategy by targeting nascent buffelgrass satellites and thereby significantly decreasing its rate of spread (Moody and Mack, 1988; Hastings et al., 2005). This strategy could be effective in areas where there is a low risk of reinvasion and encroachments from neighboring patches (Cannas et al., 2006; Lookingbill et al., 2014).

Patch expansion rate is a related and important element of reinvasion risk and dispersal strategy (Fensham et al., 2013; Lookingbill et al., 2014). Knowing patch expansion rates not only inform land managers of the resources needed to negate patch expansion (Olsson et al., 2012), but allows managers to account for expansion of neighboring patches that could become a future source population to neighboring areas and thus increase risk of reinvasion (Higgins et al., 1996; Cannas et al., 2016), particularly in a satellite-targeting control method.

Olsson et al. (2012) found that buffelgrass patches double in size an average of every 5.1 years, with a range of 2-7 years. If this doubling time is consistent with all buffelgrass invasions, there is theoretically enough time for land managers to remove satellites. However, the patches in the Olsson et al. (2012) study had colonized their study sites for 14 to 20, compared to 2-7 years on our study site on the Barry M. Goldwater Range (BMGR) in Arizona (Whittle, Personal Observation). This introduces uncertainty to the applicability of Olsson et al.'s results to new invasions because the majority of suitable habitat may have been colonized which would reduce the ability of patches to expand. This is especially relevant if satellite dispersal is used by buffelgrass, since nascent satellites might grow at a faster rate than larger patches. The purpose of our study was to determine buffelgrass dispersal pattern and expansion rate at BMGR.

Methods

Study Area

The Barry M. Goldwater Range (BMGR) offered a unique opportunity due to the recent buffelgrass invasion, first noted in 2008 (Richard Whittle, Personal Observation), providing an opportunity to analyze dispersal pattern and patch expansion during invasion. Data were collected between the road and the fence that delimits the right-of-way, an average distance of 60 meters on each side of the highway. The fence made a well-defined break between the relatively undisturbed land of BMGR and the right-of-way, which is either directly disturbed or physically changed by the road (e.g. water distribution). Data for satellite dispersal was collected along the west side of 16 km of Arizona State Route 85 that runs through BMGR, for a total area of 1 ha (Figure 1). Data for the patch expansion came from buffelgrass patch boundaries which were monitored along a 56 km stretch of State Route 85 (Figure 1), for a total area of 676 ha.

Study Area
Arizona State Route 85, Barry M. Goldwater Range

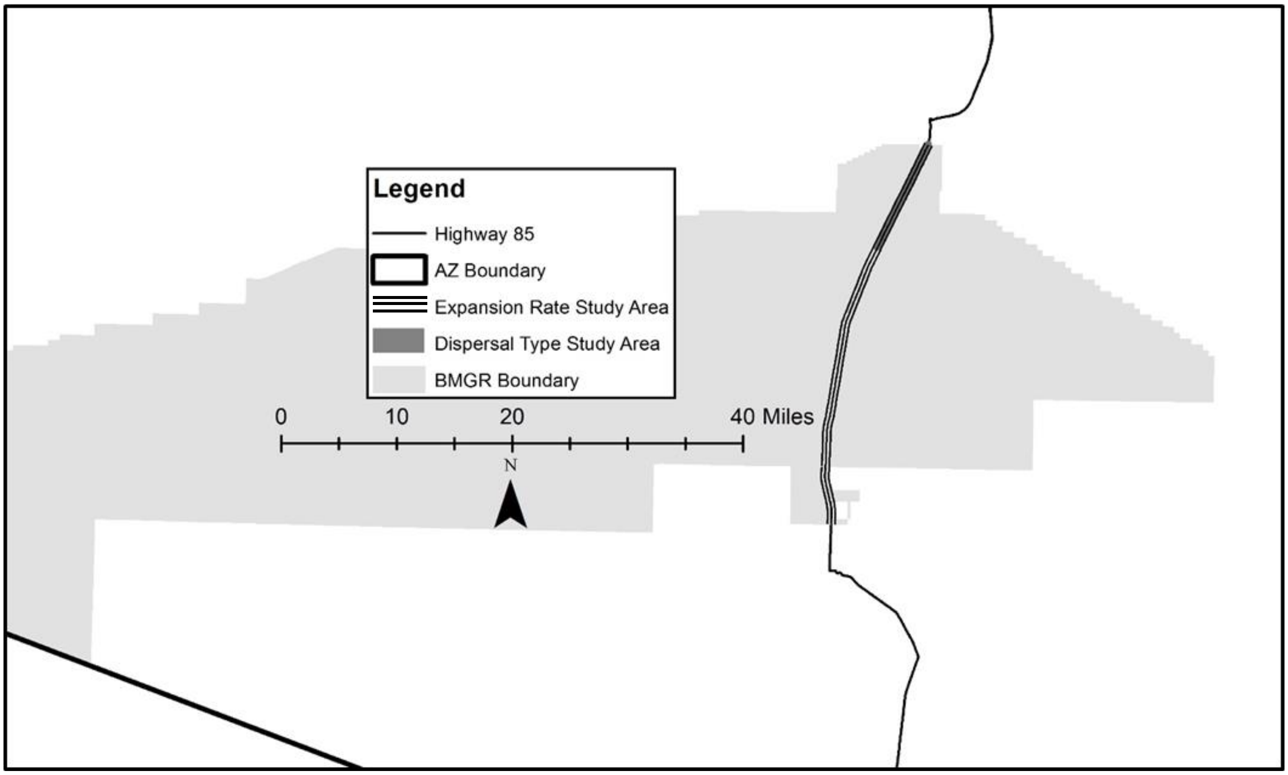

Figure 1 Map of study area in southwest Arizona

Data Collection and Analysis – Dispersal Type

In spring 2015, buffelgrass individuals were identified from the window of a vehicle driving up to 30 km/h along the west side of State Route 85. GPS coordinates were recorded for each individual (GPS 60, Garmin, Schaffhausen) in UTM WGS84 to an accuracy of ± 3 to 5 m. An accuracy assessment was conducted to evaluate identifying buffelgrass from a vehicle. Ten randomly selected, 300 m transects were walked within the study area to identify errors of omission and commission, an accuracy assessment area of 180,000 m^2.

The location of each individual buffelgrass were used to determine dispersal pattern via the native ArcGIS Average Nearest Neighbor (ANN) tool (ArcGIS version 10.2.2, ESRI, Redlands, CA). If the ANN tool classified buffelgrass spread as dispersed or random, the spread would be an invasion front. Otherwise, a clustered classification from the ANN would indicate satellite dispersion. The accuracy assessment area of 180,000 m^2 was rasterized into 180 1,000 m^2 cells and errors of omission and commission were calculated for each cell.

Data Collection and Analysis - Expansion Rate

From 2010-2013, buffelgrass patches were observed October through December using all-terrain vehicles along the east and west rights-of-way of Arizona State Route 85 that run through BMGR. Patches were defined as 3 or more individuals, ≤ 0.5m apart. GPS coordinates for patch outlines were recorded (Trimble Geo XH, Sunnyvale) in UTM WGS84 receiver to an accuracy of ± 20 cm post correction.

An exponential model was used to estimate the growth rate of each patch over the 4 years of observation in ArcGIS, based on the work of Olsson et al. (2012) Eq. (1). Buffelgrass patches were analyzed only if there were 3 or more consecutive years of data for the patch (66 patches were present for only 1 or 2 years). In this study, no patches existed all 4 years, thus all patches analyzed existed for 3 years of the study (in each case, 2011-2013). The growth factor was then calculated using a nonlinear least squares estimator in Microsoft Office Excel 2013® (Microsoft, Seattle, WA). A pooled site model (PSM) was also created by summing all patches to produce an aggregate for the entire study area (Olsson et al., 2012).

Equation 1:

$$\frac{\dfrac{log_2}{\log\left(\dfrac{1+r^2}{100}\right)}}{100}$$

Results

Dispersal Type

The Average Nearest Neighbor test classified buffelgrass spread as satellite, z-score -47.2, $p < 0.01$. A total of 652 buffelgrass individuals were identified along a 16 km stretch of State Route 85. The individuals occurred in 6 distinct patches of varying sizes (8 m^2 – 2997 m^2) varying in distance from each other (the closest patches were 0.743 km apart and the furthest patches were 12.8 km apart, based on mean center). The patches are distinctly different from a random or dispersed pattern found in an invasion front (Figure 2), confirmed by the average nearest neighbor test.

For the accuracy assessment, 3 of the 180 raster cells contained buffelgrass that were incorrectly mapped, returning an accuracy of 96.7% which exceeded the recommended level of 85% by Foody (2002). Of the 180 cells, 0 incorrectly predicted no buffelgrass, 174 correctly predicted no buffelgrass, 3 incorrectly predicted buffelgrass, and 3 correctly predicted buffelgrass.

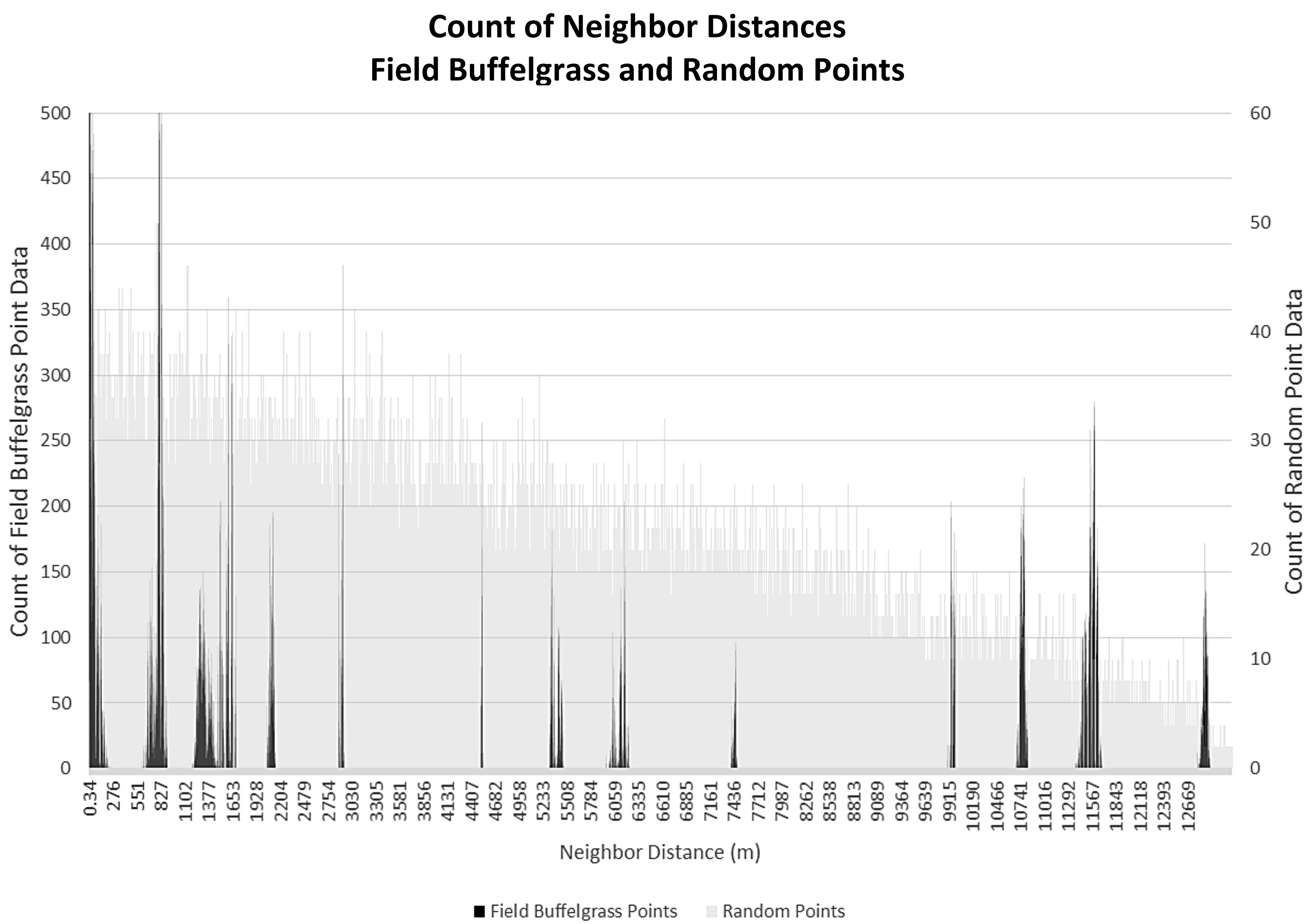

Figure 2 Histogram grouping the frequency of distances from one buffelgrass point to all buffelgrass points (in black) for each of the 652 buffelgrass points. This is contrasted with a histogram for a set of 652 randomly created points (in grey) within the study area. The buffelgrass points are in distinct groups, visualizing the satellite dispersal. The random points show a downward trend due to the oblong shape of the study area (60 m by 1600 m). The left-hand y-axis was truncated to better fit the data. Thirty-seven distances (0.001%) were above 500m and not used, as seen on the left-hand side of the graph.

Expansion Rate

We identified 36 patches along a 56 km stretch of highway 85. Buffelgrass patch expansion varied from 1.03 to 438 times the original size. Seventy-five percent of buffelgrass patches expanded more from 2011 to 2012 than from 2012 to 2013. In fact, 25% decreased in size from 2012 to 2013. The pooled-site model (PSM) – a sum of the area covered by all buffelgrass patches on the study area – increased both years, but more from 2011 to 2012 (117%) than from 2012 to 2013 (69%).

The exponential model was a good predictor of 28 (78%) of the patches; r^2 for these patches ranged from 0.73 to 1.000, averaging 0.87. The r^2 for the remaining 8 patches ranged from 0.01 to 0.69, averaging 0.02. For the 8 patches with a low r^2, each patch decreased in size from 2012 to 2013 (each of these patch decreased between 6 - 60%).

The average doubling time of patches, 5.1 years, was heavily skewed by 3 outliers (of 36 total patches) of 23.5, 51.2, and 71.9 years. Removing those outliers, the average doubling time was 1.2 years. The doubling time for the PSM (0.70 years) was faster than the average of individual patches (5.1 years for all and 1.2 years without the outliers), showing that buffelgrass expansion on the entire site was much faster than the average expansion of individual patches.

Discussion

Dispersal Type

The average nearest neighbor test in this study indicates a satellite dispersal strategy. Although buffelgrass has been shown to establish patches (e.g. Olsson et al. (2012) and Rogstad (2008)) – an indication of satellite dispersal, a link between satellite dispersal strategy and buffelgrass invasion has not been previously established. Moody and Mack (1988) found that targeting satellites improves the control of a plant invasion for an area, if a minimum of 15% of satellites are removed. Without satellite control, Moody and Mack (1988), Shigesada and Kawasaki (1997), and Cannas et al. (2006) found that plant invasions spread exponentially faster, a substantial consequence to land managers. This represents an opportunity to improve buffelgrass control on large areas by incorporating satellite targeting into a control strategy. However, managers face the difficulty of finding satellites that are small enough to control, yet on areas with low likelihood for reinvasion (Lookingbill et al., 2014).

Expansion Rate

Each patch increased in size during the entire study time from 2011 to 2013, although two patches increased by less than 10%, at 3% and 6%. Some patches, however, disappeared, especially when considering patches that were not present for all 3 years. This behavior is not unexpected at such a small scale because of micro-variabilities in space (e.g. landscape) and time (e.g. Chabrerie et al. (2007) and Janišová et al. (2012) found that *Prunus serotina* and *Tephroseris longifolia*, respectively, varied in distribution and cover as a response to environmental characteristics). In the present case, higher precipitation in 2011 could be the reason for the greater growth in the first year compared to the second year (data.gov, 2016).

Buffelgrass patch expansion variability in this study aligns with the descriptions of Johnson and Shonkwiler (1999) on expansion rates, who describe patch expansion as variable over time because of environmental factors. Schramm and Ehrenfeld (2012) similarly found that patch expansion varied during a *Microstegium vimineum* invasion, particularly in the direction that patches expanded. Most important, however, the results of this study corroborate Olsson et al.'s (2012) findings on buffelgrass expansion, who also found that buffelgrass patches decreased in size in different time periods, even given the longer duration of their study. For example, one patch decreased in size between 1990 and 1993 and another decreased in size from 1994 and 1997.

The present study differed, however, with Olsson et al.'s (2012) results in doubling time, which ranged from 2-7 years (average 5 years) compared 1-71 years (average 5 years) in the present study. Removing the 3 outliers mentioned in the results, the doubling time found in our study was 1-6 years (average 1 year), suggesting that expansion rate for new invasions is higher than established patches. The expansion of the pooled site model further illustrates this point. The PSM (i.e. the combined area of all buffelgrass) of the present study expanded 8.33 times faster than Olsson et al. (2012) (0.70 year versus 5.82 year doubling time).

Patch coalescence is another important behavior during an invasion because it represents a shift from invasion to expansion and connectivity of patches, leading to manifold increases in the impact a species has on the environment and increasing the invasion rate to neighboring areas (Davis et al., 2004; Liebhold and Tobion, 2008). Albeit at a micro-scale, coalescence was observed during the study period. In the most extreme case, the largest patch on BMGRE began as 34 separate patches in 2011, down to 11 patches in 2012 (because of coalescence and spawning of new patches), and finally coalesced to one single patch by 2013.

Relevance to Land Managers

To create control strategies, managers typically rely on models to project an invasive species' behavior, such as expansion rate, under different management and environmental scenarios (Eisworth and Johnson, 2002). The expansion rates found in this study can be used to improve model projections for buffelgrass, as land managers expect buffelgrass to continue spreading rapidly (Rogstad, 2008). Given the faster expansion rates found in this study compared to Olsson et al. (2012), our results are particularly relevant to updating model spread rates of nascent buffelgrass populations. Previous research (Moody and Mack, 1988; Higgins et al., 1996) has used modeling to shown the benefit of including satellite dispersal pattern into management strategies, representing another opportunity for land managers to modify buffelgrass models based on the results of this study.

Caveats and Future Research

The study areas' small size and landscape features (i.e. right-of-way) limits the applicability of this study's results and underscores knowledge gaps related to buffelgrass patch expansion and dispersal strategy. Regarding patch expansion, the contrast in results between this study and Olsson et al. (2012) indicates a possible significant difference between patch expansion rates of nascent versus established buffelgrass patches that could affect the development a control strategy. Given the limitations of the present study area, however, research on a larger, more representative site is needed to verify the results of this study at a meaningful scale. Linking patch expansion to environmental variables, such as temperature and weather, would further improve buffelgrass invasion models. The results from the satellite dispersal analysis would similarly benefit from research on a larger, more representative area, in addition to a long-term study documenting buffelgrass dispersal type.

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