A Desert Invader: Stinknet Success Factors
Final Report for Grant Agreement No. VMG 24-101

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Background

Stinknet (*Oncosiphon puliliferum*) is an annual forb native to South Africa. Since its introduction to California in the 1980s, it has expanded into Arizona and established as an invasive species. This has posed a significant concern among land managers, given its rapid success and potentially negative ecological interactions. Understanding of what facilitates stinknet invasion in the Sonoran Desert is under-developed, creating a challenge for land managers trying to control its spread. To inform decisions about stinknet control, it is important to better understand what environmental properties are associated with the spread of stinknet, including its interactions with soil resources and other members of the plant community.

In Fall 2024, we were awarded a $3,000 grant to conduct research to explore the ecological context of the invasive plant stinknet. Our proposal focused on the identification of stinknet's competitive interactions with native plants and the plant-soil relationships through which the competition might occur. We proposed to address this through two research questions:

Research question 1: What species of native plants are best able to outcompete stinknet during restoration (thus preventing stinknet from re-establishing after removal)?

Research question 2: By what mechanisms are stinknet vs. native plants able to competitively exclude the other?

We proposed a two-part research plan that combined observational field work using paired invaded and non-invaded plots at three Maricopa County Regional Parks with experimental work using collected stinknet seeds in a greenhouse growth experiment under controlled conditions.

Initial Field Work

The proposal was funded in Fall 2024 for implementation during the Spring 2025 desert annuals growing season that follows the Sonoran Desert winter rains. However, winter precipitation during late 2024-spring 2025 was very low, and subsequently stinknet emergence was low. While we were able to conduct the planned plant and soil analyses at one paired site at Cave Creek Regional Park, we were unable to locate a statistically robust number of appropriately-sized invaded plots with current growth at a spatial scale to meet our research plan. Subsequent collection of seeds was therefore also not possible for the greenhouse study.

Preliminary results from Cave Creek Regional Park suggested lower soil NO_3^- and higher PO_4^{3-} in stinknet-invaded soils, reflecting that the presence of stinknet is correlated with altered soil nutrient availability (Fig. 1). There was also a slightly less abundant soil mesofauna community associated with stinknet invasion (Fig. 2). Despite these differences in soil resources, there was no significant difference between stinknet-invaded and uninvaded plant community diversity, as measured through Shannon-Wiener Diversity Index (P = 0.717),

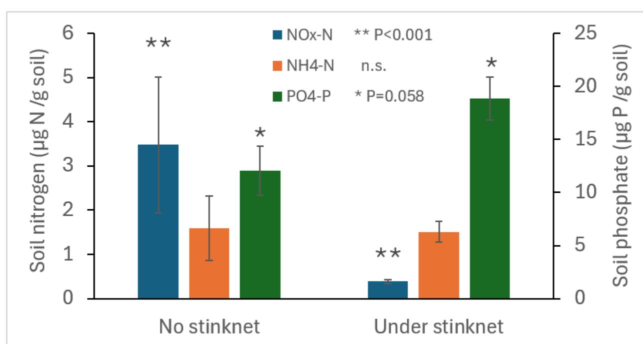


Figure 1. Soil mineral nutrient content under both non-invaded and stinknet-invaded plant communities at Cave Creek Regional Park.

Simpson's Diversity Index ($P = 0.822$), or evenness ($P = 0.947$). However, these results are specific to that one site, and not spatially extant enough to make broad conclusions about stinknet plant-plant and plant-soil interactions.

Rather than delaying the project by a year to Spring 2026, we leveraged existing data collected by the Central Arizona-Phoenix Long-Term Ecological Research program (CAP-LTER) to address our research objectives in a statistically robust manner. The remaining funding was used to pay the wages for an Environmental Science student at Arizona State University to perform the very time-consuming task of building the databases for subsequent analysis using the archived data.

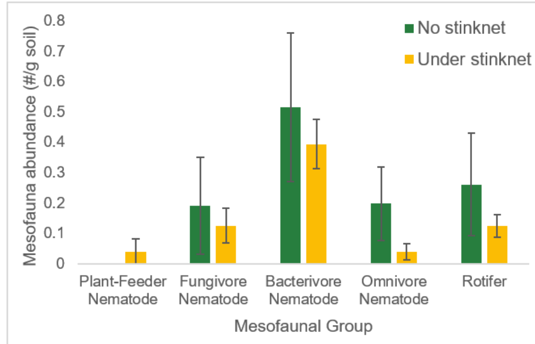


Figure 2. Soil mesofauna community abundance under both non-invaded and stinknet-invaded plant communities at Cave Creek Regional Park.

About CAP-LTER

CAP-LTER is a National Science Foundation funded program that advances research and education on urban ecology and urban socio-ecological systems. As part of the US-wide LTER network, it is one of two LTER sites in the desert southwest and one of two that specifically studies urban ecology. The CAP-LTER study site encompasses the urban area of Phoenix, AZ, including its 5 million residents, as well as native Sonoran Desert and agricultural land. Funded since 1998, the CAP-LTER conducts numerous observational and experimental studies that provide a temporally continuous quarter-century of data from a spatially expansive area in the rapidly urbanizing Sonoran Desert landscape. This includes measurement of annual plant communities, which, given the time frame of operation, incorporate the arrival and spread of stinknet in the study area.

Two CAP-LTER datasets were used to investigate the environmental conditions around stinknet arrival and spread throughout the Phoenix Metropolitan Area: the Ecological Survey of Central Arizona (ESCA) and the Desert Fertilization Experiment (DesFert). Publications from both of these datasets are currently in preparation for submission to peer reviewed journals, by the end of summer 2026.

Ecological Survey of Central Arizona

ESCA is an extensive field survey that inventories a broad array of soil, plant, and organismal parameters at sites across the diversity of land uses in metropolitan Phoenix and the surrounding Sonoran Desert. It is conducted every five years at the same 150+ locations since it began in 2000, capturing a quarter century of land use change across the region. Sampling sites were chosen using a probability-based design to achieve spatially dispersed, unbiased representation of the land cover in the study area. We established a permanent 30 m × 30 m plot around the predetermined coordinates as the center points oriented directly north, south, east, and west from the center. Land use for each site was described in the field at the time of sampling by recording the land use code, according to the classification scheme utilized by the Maricopa Association of Governments (MAG). Land cover fluctuates over the duration of this study, and at any given point is composed of Sonoran Desert (35-45%), turfgrass lawn (6-11%; in residential, municipal/industrial, golf courses), managed xeric landscapes with drought-tolerant vegetation and rock ground cover (13-19%; in residential, municipal/industrial, transportation corridors), agriculture (8-10%), bare ground (7-9%; in vacant lots, dirt roads), water (1%; in canals, streams), and impervious surface (12-22%).

Soils were collected over a 3-4 month period in 2000, 2005, 2010, 2015, and 2023 (delayed from 2020 due to COVID-19 restrictions). Detailed methods can be found on the publicly-available metadata, but in brief: Soil cores to 30 cm depth were collected in plastic liners using a 2.5-cm diameter slide-hammer corer from non-paved areas at four points in each plot. The sampling locations were moved 0.5 m clockwise from the cardinal directions in each subsequent years to avoid resampling the same disturbed soil from previous years. These cores, for soil chemical analyses, were separated back in the laboratory into two depths, 0-10 cm and >10 cm (to the bottom of the core), and the four cores per plot were homogenized in each depth category for determination of soil properties and chemistry including mineral N (NH_4^+-N and NO_3^-+NO_2-N), phosphate (PO_4-P), % total C and N, % organic C, % inorganic C, soil organic matter (SOM) content, and soil water content (SWC). One additional 5 cm diameter core was taken from near the plot center, up to 1 m away in a different cardinal direction each year, for determination of pH, electrical conductivity (EC), bulk density, and soil texture.

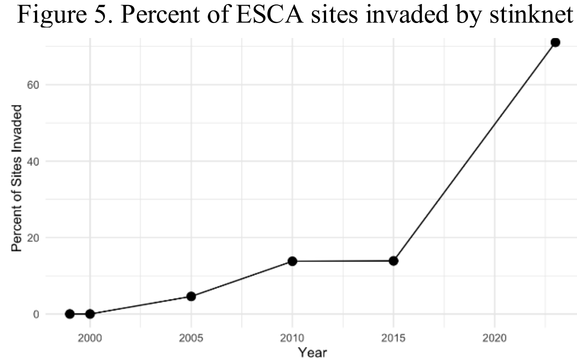
Annual plant community composition was determined at each of the sampled plots by linear extent using two transects bisecting the 30 m x 30 m square plots, one running north-south and one east-west. Coverage was measured in 0.25 m increments along the transects, with each annual plant intersecting the transects identified to the lowest taxonomic level possible in the field, generally to species. The linear extent of each species along the two transects was then used to average the percent cover of the species within the 30 m x 30 m plot.

Stinknet was first detected in ESCA sites in 2005, suggesting its arrival sometime between 2000-2005. Since then, it has risen to be present at 70% of sites by 2023 (Fig. 5). Stinknet was found at just over 50% of desert sites (Table 1). Equally invaded are the urban land uses where plant resources are available but weed control is limited (turf grass-dominated golf courses and city parks, vacant land), followed by general urban land uses (a mix of industrial, institutional, and commercial land) and roadsides with lower resources but still limited weed control. Stinknet was least frequent in land uses where herbicides for weed control are common: residential yards and agricultural land.

Table 1. Site-level invasion of stinknet across broad land use categories, summed across all years of the study.

Land use	# Sites	% Invaded
Desert	76	56.6
Golf Course/Park	8	50
Vacant	12	50
Urban	37	40.5
Transportation	10	30
Residential	73	21.9
Agriculture	23	21.7

Figure 5. Percent of ESCA sites invaded by stinknet



Soil chemistry did not strongly differ where stinknet was present compared to those without stinknet. When viewed across all 150+ sites, soils without stinknet are comprised of a broader range of soil chemical values given the wide range of land uses, and stinknet-invaded soils overlap within a slightly more narrow range of that soil chemistry (Fig. 6). Even when broken down to consider soil chemistry within specific land uses, PERMANOVA does not detect a significant difference in soil chemical makeup between stinknet invaded and non-invaded sites. This suggests that there are not particular soil chemical parameters that are associated with stinknet, either as conditions that promote stinknet presence or by being altered after stinknet invasion.

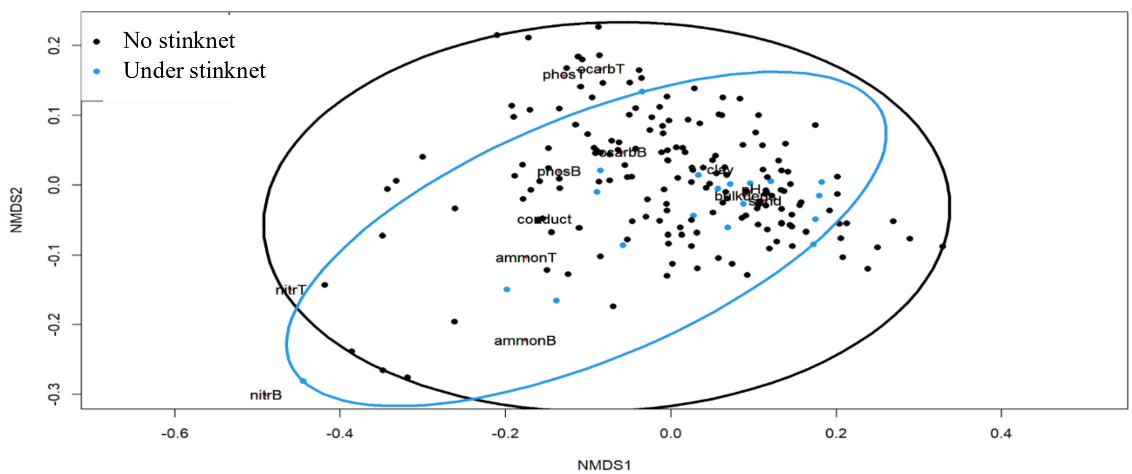


Figure 6. Non-metric multi-dimensional scaling (NMDS) of soil chemical properties in the surface and bottom depths of soil across the CAP-LTER study area. Soil chemical parameters include mineral forms of plant-available nutrients (nitrate, ammonium, phosphate) and carbon in both the Top (T) and bottom (B) soil layers, as well as texture (clay, sand), bulk density, and pH.

Thus, the ESCA data suggest that stinknet is capable of establishing across a variety of environmental conditions in the Phoenix metropolitan area. Rather than being related to soil resources or specific habitats, its presence is recorded more frequently in land-use types associated with the lack of weed control efforts. This broad habitat envelope makes stinknet difficult to control by managing soil conditions or plant communities to exclude stinknet.

Desert Fertilization Experiment

The DesFert project was established in 2006 to better understand the biogeochemical pathways that result from elevated inorganic nitrogen deposition from the atmosphere. It is conducted at 15 desert sites in the Phoenix Metropolitan Area: 5 desert remnant parks within the urban core and 5 desert parks each in the exurban areas to the west and east of the city. At each site, five permanent 20 m x 20 m plots were established, one for each of three fertilization treatments and two control plots receiving no fertilization. Fertilization treatments consisted of either nitrogen ("N" plots), phosphorus ("P" plots), or combination ("NP" plots) fertilization as hand-broadcast solids twice annually, once between December and February and once between June and August to follow the first winter and summer rains, respectively. Nutrient amendments consisted of solid ammonium nitrate (NH_4NO_3) on N and NP plots, and triple super-phosphate on P and NP plots.

Beginning in spring 2009, CAP LTER began surveys of annual plant community composition. Detailed methods can be found on the publicly-available metadata, but in brief:

Within each of the experimental plots, four subplots measuring 1 m x 1 m were established within each of four main plots (N, P, NP, and one control plot) using randomly selected locations within the main plot. Subplots were established with their corners approximately aligned to the cardinal directions and were split between two microhabitat types: two under creosote shrub canopies and two in interplant areas. Annual plant community composition surveys were conducted at peak herbaceous biomass (generally in March, with survey dates ranging from late February to early April over the span of study). Subplots were surveyed to estimate percent cover, assessed from a 2-D “birds-eye view” perspective, of annual plants identified to the lowest feasible taxonomic level (generally to species, with some to genus).

Precipitation data were downloaded from the Maricopa County Flood Control District rain gauges (https://www.maricopa.gov/625/Rainfall-Data). Daily precipitation data were downloaded for the 2-3 rain gauge stations closest to each study site and averaged. These daily averages for each site were summed from October 1 to March 30 to encompass winter precipitation for each site.

Stinknet first appeared in the DesFert research plots in 2015, and thus our analyses focus on the decade from 2015-2025. Stinknet presence and abundance was strongly influenced by

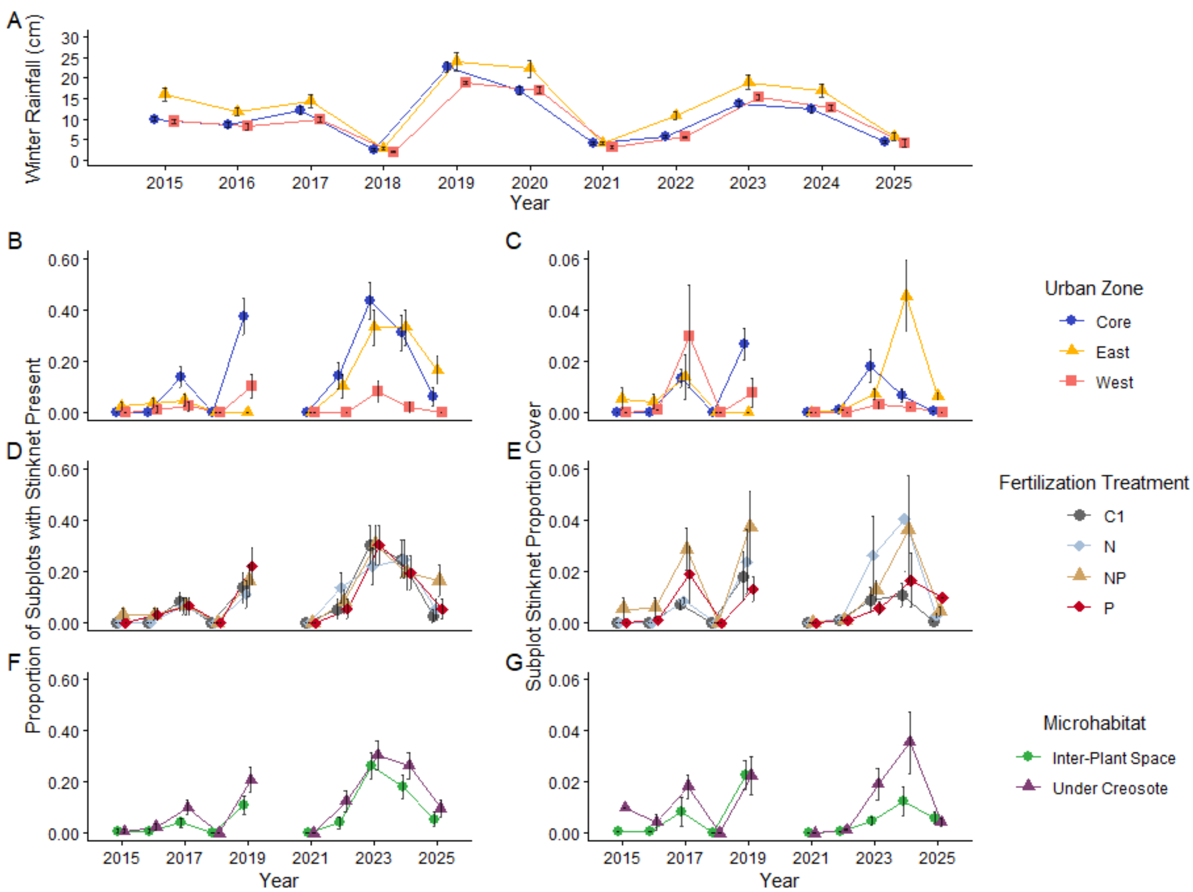


Figure 3. (A) Mean annual winter rainfall across all sites. Left-side panels (B, D, F) display mean annual proportion of subplots with stinknet present, while right-side panels (C, E, G) display mean annual stinknet proportion cover within subplots. Both columns are broken out by urban zone (B-C), fertilization treatment (D-E), and microhabitat (F-G). Note: no observations for 2020 were included in the dataset due to limitations stemming from the COVID-19 pandemic resulting in only 32 out of 1440 subplots being measured that year. All error bars represent ± SE.

winter precipitation, where springs growing seasons that were preceded by very low winter precipitation (e.g., the springs of 2018, 2021, and 2025) have very low stinknet presence and cover (Fig. 3). Similar to the ESCA dataset, about 50% of desert subplots have been invaded by stinknet. Stinknet is more frequently present in the urban core and east of the city compared to west (Fig. 3B). Its frequency east of the city is likely the result of the higher precipitation in that region, but precipitation alone does not explain its frequency inside the urban core, and is therefore more likely the result of increased human activity to transport the seeds. While urbanization makes stinknet more likely to be present, its abundance when present (measured as proportion cover) is not clearly driven by urbanization, with a lot of interannual variability in which urban zone had high cover (Fig. 3C). Fertilization did not influence the likelihood for stinknet presence (Fig. 3D), while it had a moderate but not significant influence on extent of cover (Fig. 3E). When winter rains were sufficiently high, the N+P treatment tended to increase stinknet cover, though with high variability among sites. Finally, the microsite conditions beneath creosote shrubs marginally increased the likelihood for stinknet to be present (Fig. 3F), but significantly increased stinknet cover when present (Fig. 3G), demonstrating that the shade, hydraulic lift, and overall altered microclimate from shrub nurse plants facilitates stinknet growth.

A binomial general linear mixed-effects model of stinknet presence found that, in addition to a significant effect of winter rainfall ($P < 0.001$) and shrub microhabitat ($P < 0.001$) visible in Fig. 3, historical presence of stinknet at the site within the preceding five years was a statistically significant predictor of stinknet presence ($P < 0.001$). This historical presence reflects the seedbank left by stinknet plants that, according to the literature can persist for at least five years, outlasting years of low precipitation.

We further investigated the correlation between stinknet cover and that of all other annual plants, both at the species and genus level. The analyses included species that comprised at least 20 observations over the 10 years of data and a maximum proportion coverage in any particular subplot-year pairing of at least 0.02. Only positive correlations were found between stinknet and other annual plant species, though none of them are very strong (Fig. 4A). This likely reflects the fact that many Sonoran Desert species respond positively to the same resource limitations as stinknet. We also investigated relationships at the genus level, including only those genera with a combined total of at least 30 observations and combined maximum proportion cover of at least 0.04. At this level, again most correlations were weakly positive (Fig. 4B). The genus

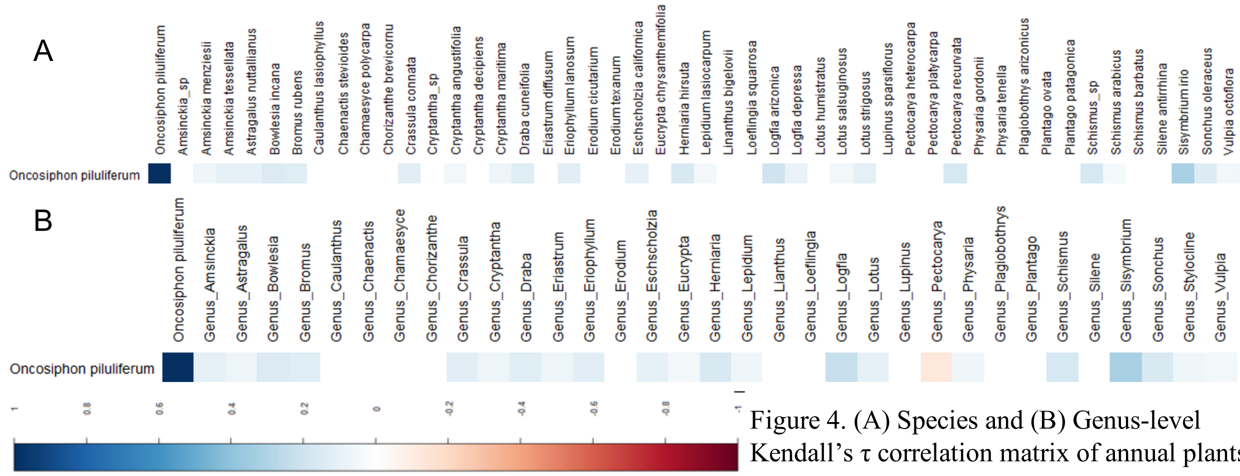


Figure 4. (A) Species and (B) Genus-level Kendall's τ correlation matrix of annual plants. Only significant (p ≤ 0.05) correlations are colored.

Pectocarya did have a weakly negative correlation with stinknet, but interestingly this was not visible when considering individual species in that genus. This is, however, a correlation and it is not possible to assess from these data which one of the two species is causing the decline in the other, i.e. whether stinknet outcompetes *Pectocarya* or vice versa.

Recommendations

Stinknet poses a difficult management challenge. Using 25 years of data that encompass the arrival and spread of stinknet in the Phoenix Metropolitan Area, it is clear that stinknet proliferation is largely dependent on dispersal by human activity and precipitation. It is most frequent in the urban core with higher human activity and to the east with greater precipitation, and its interannual variability corresponds to that of winter rainfall. Because precipitation is obviously outside of land managers' control, there is no easy point of intervention to prevent the arrival of stinknet into a parcel of land. Stinknet is not selective in the soil parameters needed for establishment and survival, existing in and around Phoenix over a broad range of soil chemistry and not responsive to fertilization. There are no strongly negative correlations with any native plants, and shrub species actually facilitate stinknet, so manipulation of soil habitat and plant communities are not likely going to successfully prevent or reduce the spread of stinknet.

Our evidence suggests that weed management is the main characteristic that reduces stinknet presence. Of the array of land uses captured in our data, the only sites that maintain lower rates of stinknet presence (beyond those that have low precipitation rates) typically utilize broad-spectrum herbicides regularly across the site to control weeds: agricultural land and residential yards. Herbicides are sometimes used by land managers to remove stinknet, but seek ways to reduce re-establishment after that treatment. Due to stinknet's broad environmental tolerance, our data are not able to identify a specific soil condition or plant community that would exclude stinknet from re-establishing, suggesting that these forms of post-herbicide restoration will not constitute a successful use of resources.

Notably, the seedbank is a main concern in post-treatment areas, given that historical presence within the past five years is equally important as precipitation in determining stinknet presence. Thus, a main recommendation from our results is that infrequent, one-seasons worth of mechanical or chemical treatments to remove stinknet plants is not sufficient to reduce its success. Removal of adult plants needs to be followed by many years' of continued treatment that either prevent or exhaust the seedbank until emergence ceases (e.g., via pre-emergent herbicide known active against stinknet, or consistent repeated manual removal of new plants prior to any/all seed production).

Acknowledgements

Support provided in part by funding from the Southwest Vegetation Management Association's Grant Program. Two different manuscripts resulting from this body of work are in preparation for peer review later this year.