An Examination of Plant-Animal Interactions in a Desert Ecosystem

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Table 1: Timeline for Ph.D. Research 2022/2021

Chapter	Title	Progress	Short Term Goals	Long Term Goals
1	A meta-analysis of shrub density as a predictor of animal abundance	The meta-analysis for this project has been completed and analyzed. The manuscript has been completed and was submitted to Wildlife Biology and is currently under review.	Address any revisions Wildlife Biology may have on the submitted manuscript and continue the publication process.	Have this project completed and published before the end of summer 2022.
2	The impacts of temperature on the germination of native versus exotic desert annuals	The trials for all 4 plant species have been completed, data has been inputted into R and we are currently analyzing the data and generating figures.	Complete data analysis for this project and begin writing the manuscript by the middle of July 2022.	Have a completed and edited final version of a manuscript ready and send out for publication by the mid to end of August 2022
3	Shrub density effects on an endangered lizard of the Carrizo Plain National Monument, California	All lizard and shrub data have been collected and compiled. The manuscript has been written for this project and has been submitted to Ecosphere for publication.	Complete any revisions Ecosphere may have for the submitted manuscript and continue the publication process.	Have this project completed and published before the end of summer 2022.
4	The influence of shrub density on local vertebrate association across varying ecosystems	We have completed the field work for this chapter, from May – to June 2022. All camera trap photos and temperature data have been downloaded and are being prepared for processing.	Have all camera trap files processed by the end of summer 2022. Begin generating figures and running statistics by October 2022.	Have a completed and edited final manuscript ready to send out for publication by the end of November 2022.
5	The effect of shrub loss and introduction on animal community assembly	We are currently planning on running this project during field season 2023. All camera traps and temperature loggers have been purchased and are ready.	Apply for permits to remove shrub individuals and prepare materials for field deployment.	Return summer 2023, begin going through camera trap photos and start data analysis.

Background:

The biodiversity of ecosystems can be significantly influenced by plant-animal interactions. These interactions can enhance the overall natural system through beneficial ecological functions (Tilman et al. 2014, Lortie et al. 2021) or have negative impacts such as the invasion of a species. Plant-animal interactions are evident almost globally in all ecosystems and are defined as non-trophic interactions between individuals where one of the interacting species has a positive benefit, while the other remains unaffected (Bertness & Callaway 1994, Molina-Montenegro et al. 2016). One of the more common types of positive interaction between plant and animal species is facilitation, otherwise known as commensalism, where one of the interacting species benefits while the other receives no benefit nor experiences any negative effect from the interaction (Kikvidze & Callaway 2006; Araújo & Rozenfeld 2013; Kéfi et al. 2016). In arid/semi-arid ecosystems, these types of interactions often occur at higher frequencies as the associated benefits increase species survival (Holzaphel & Mahall 1999, Stachowicz 2001). It has been proposed that without these interactions, the harsh conditions can have detrimental effects on both plant and animal survival (Holzaphel & Mahall 1999; Lortie et al. 2016). In addition, the increasing severity of climate events such as drought, brought on by climate change, can further the reliance on these facilitative interactions within harsh arid/semi-arid ecosystems (Callaway et al. 2002; Westphal et al. 2016; Dangles et al. 2018).

Foundational species are defined as species that: (1) are both abundant and comprise most biomass in an ecosystem, (2) they are at or near the base of interactions, and (3) have an abundant connection to several other plant and animal species (Ellison 2019). In desert ecosystems of Southern California, the shrub species *Ephedra californica*, acts as a foundational species that mediate positive interactions (Lortie et al. 2016; Filazzola et al. 2017). These shrubs act as keystone species, species that are in great abundance within an ecosystem helping in the maintenance of the habitat and biodiversity, allowing for facilitation interactions to occur (Bond 1994; Soulé et al. 2005; Filazzola & Lortie 2014; Lortie et al. 2018). Direct positive interactions from these shrubs influence animal communities through various mechanisms such as: acting as a source of food (Parmenter & MacMahon 1983; Auger et al. 2016), shelter from potential predators (Greenfield et al. 1989, Vázquez et al. 2009, Lortie et al. 2018), and thermoregulation (Noble et al.2016, Westphal et al.2018; Ivey et al. 2020). Specifically, the microclimate under these foundational shrubs is more advantageous for proper thermoregulation and escape from harsh abiotic conditions (Ivey et al. 2020, Zuliani et al. 2021). These mechanisms drastically impact the survival of a species and influence local animal associations, thus impacting local community composition (Hughes 2012, Rey et al. 2018).

Endangered species in particular such as *Gambelia sila*, the blunt-nosed leopard lizard, utilize these positive associations with shrubs to aid in their overall survival. These benefits are then indirectly reciprocated by animal species through the dispersal of seeds and consumption of harmful animal and/or plant species (Vázquez et al. 2009, Lortie et al. 2016). These shrubs also benefit native and invasive plant species under their canopies (Badano et al.2016; Lucero et al. 2019). Invasive plant species, such as *Bromus rubens*, *Bromus hordeaceus*, and *Schismus barbatu*, positively associate with foundational shrub species, while negatively impacting annual communities by outcompeting for resources (Lucero et al. 2019). These positive interactions promote the success of these invasive species showing the potential dark side of this type of interaction (Simberloff 2006; Lucero et al. 2019). However, these foundational shrubs provide direct benefits to native plant communities through temperature amelioration, seed trapping, and herbivory protection, thus increasing the biomass of understory vegetation (Bullock & Moy 2004; Lortie et al. 2018, Filazzola & Lortie 2014). The positive benefits experienced by local animal and plant species may be associated with the density-dependent associations seen with *Ephedra californica* individuals. *Ephedra californica* is the dominant foundational plant species in The Carrizo Plain National Monument (Lortie et al. 2018, Filazzola et al. 2018).

Environmental stress potentially has a negative impact on organisms in an ecosystem. These stressors are typically defining abiotic features of an ecosystem, such as extreme temperatures and amounts of precipitation (Lortie et al. 2016; Westphal et al. 2018; Moore et al. 2018). These conditions in high-stress environments have substantial impacts on the survival of species. Many local species rely on the amelioration of these high-stress conditions through facilitation with foundational species (Ivy et al. 2020). This directly connects to the Stress-Gradient Hypothesis, where high-stress environmental factors, such as temperature extremes, level of precipitation, and availability of nutrients, will alter the behaviour and interactions between organisms (Bertness & Callaway 1994; Butterfield et al. 2016). In these situations, the frequency of competitive behaviors may reduce, while positive interactions will become more evident (Turner et al. 1966; Bertness & Leonard 1997). A reduction in negative interactions between individuals is more likely, where facilitative interactions are more beneficial for an individual's survival (Bertness & Leonard 1997; Hart & Marshall, 2013; Dangles et al. 2013). Since climate is a high-impact abiotic stressor on ecosystems, greater emphasis has been placed on facilitative interactions that could aid both plant and animal communities (Brooker et al. 2007; Dangles et al. 2018).

Density is a simplistic measure that is well established in competition theory with plants (Antonovics & Levin; 1980) and animal species (Adams & Walters 1995), however, density is not typically reported in facilitation studies. Shrub density can influence inter and intraspecific interactions between plant and animal communities (Springer et al. 2003; Tietje et al. 2008; Zuliani et al. 2021). Since these foundational shrub species interact with local plants and animal species (Hughes 2012), the density of these shrubs can influence local population dynamics. In terms of shrub-animal and shrub-plant interactions, density of these foundational shrub species can positively influence the net outcome of interactions with other species (Springer et al. 2003; Tietje et al. 2008). Over time, areas with relatively low number of shrub individuals will increase in density and overall shrub size (Musick et al. 1998). This results in a phenomenon known as shrub encroachment, where there is an increase in woody and/or shrub plants resulting in significant changes in total vegetation cover (Van Auken 2009; Eldridge & Soliveres 2015). While this increase in shrub vegetation is beneficial for woody plant species, typically the herbaceous layer of the ecosystem is negatively impacted by a decrease in abundance (Van Auken 2009; Maestre et al. 2016). Shrub encroachment typically has negative impacts on an ecosystem as it is associated with desertification (Van Auken 2009); however, this increase in shrub density in scrublands can enhance these ecosystems by increasing the likelihood of facilitative interactions (Van Auken 2009; Eldridge & Soliveres 2015). In these arid scrublands, such as the Carrizo Plain National Monument, increase in density increases both species abundance and richness (Zuliani et al. 2021), while potentially reversal of desertification (Maestre et al. 2009; Sirami et al. 2009). Shrub density can alter the overall animal densities in an ecosystem, suggesting that shrub encroachment can impact local vertebrate species (Skarpe 1990).

The purpose of this thesis is to explore the relationship between the density of the foundational shrub species *Ephedra californica* and the populations of both local animal and plant species. These projects all relate to density-dependent interactions in desert ecosystems and turn, can be used in other systems globally. Combining density with facilitative interactions can potentially drive restoration and land management practices. This Progress Report will outline these 5 projects and their current progress to date.

Table 2: Theory Table displaying the major theories highlighted in this thesis and their associated projects.

Theory	Description	Associated Experiments	Major Literature
Plant-animal interactions influence the population and community dynamic	Both the positive and negative interactions associated between species impact the overall abundance and richness of a community.	**Chapter 3:** Shrub density effects on an endangered lizard of the Carrizo Plain National Monument, California **Chapter 4:** The Influence of high shrub Density on local vertebrate association across varying ecosystems **Chapter 5** The effect of shrub loss and introduction on animal community assembly	Bertness & Callaway (1994) Strauss & Irwin (2004) Vázque et al. (2015)
Foundation Species Theory	This theory predicts that some plant species are fundamental to the biodiversity of an ecosystem. Some key species provide benefits to other plants that aid in the overall growth and development of other major plant species.	**Chapter 1:** A meta-analysis of shrub density as a predictor of animal abundance **Chapter 2:** The Impacts of Temperature on the Germination of Native Versus Exotic Desert Annuals **Chapter 4:** The Influence of high shrub Density on local vertebrate association across varying ecosystems **Chapter 5**: The effect of shrub loss and introduction on animal community assembly	Ellison et al. (2005) Svenning et al. (2014) Ellison (2019) Lucero et al. (2019)
The Stress Gradient Hypothesis	As the overall stress of an ecosystem begins to rise, such as temperature extremes, varying nutrient levels, soil moisture, and presence/absence of water, we will see an alteration in the interactions between organisms. Positive interactions become more significant, while negative interactions become less prevalent.	**Chapter 2:** The Impacts of Temperature on the Germination of Native Versus Exotic Desert Annuals **Chapter 3** Shrub density effects on an endangered lizard of the Carrizo Plain National Monument, California **Chapter 4:** The Influence of high shrub Density on local vertebrate association across varying ecosystems **Experiment 5**: The effect of shrub loss and introduction on animal community assembly	Bertness & Callaway (1994) Maestre et al. (2009) Dangles et al (2018) Lortie & Callaway (2006)

Chapter 1: A meta-analysis of shrub density as a predictor of animal abundance.

Purpose:

To test if shrub density and animal abundance correlate for conservation and restoration practices.

Hypothesis:

Shrub density can be used as a direct proxy in predicting local animal abundance, while this relationship is ecosystem-specific.

Progress to date:

We have completed the literature review and have extracted all usable data from the eligible paper. This data has been analyzed and figures have been generated along with their corresponding statistics. The manuscript has been completed, and edited and is currently under review at Wildlife Biology. The manuscript for this chapter has been provided separately from this document.

Chapter 2: The impacts of temperature on the germination of native versus exotic desert annuals

Chapter Rational:

Within high-stress ecosystems, such as the Carrizo Plain National Monument, the temperature has a significant influence on the growth and succession of local plan species (Bertness & Callaway 1994; Butterfield et al. 2016). These high-stress factors become more prevalent as global warming intensifies, increasing the likelihood of extreme heat and drought events (Westphal et al. 2016). However, the temperature underneath shrub canopies are typically cooler and more favorable for the growth and survival of vegetation (Holzaphel & Mahall 1999; Ghazian et al. 2020). In these high-stress ecosystems, individuals will opt for a more facilitative interaction rather than competing with one another (Maestre et al 2009). This concept is referred to as the stress gradient hypothesis, where more net positive interaction will be favored over negative interactions (Bertness & Callaway 1994). Furthering the understanding the effects of increasing temperatures could provide further insight into the succession and establishment of these plant species.

Within the Carrizo Plain National Monument there are several species – both native and exotic – that can localize under shrub canopies as well as in open areas. *Salvia columbariae*, more commonly known as chia, or desert chia, is a native annual to areas of both Southern California and Northern Mexico. This species thrives in harsh arid conditions, such as the open areas of the Carrizo National Monument, while also being able to survive and grow under shaded regions (Adams et al 2005). This species typically grows between 10 to 50cm and will produce a pale blue and purple flower when fully grown. *Layia platyglossa*, also known as tidy tips, is another native species of annual located in the arid ecosystems in California. This species' blooming season ranges from March to June and can survive both in open dry areas and has been found under shaded regions. This annual is typically distinguished by its daisy-like flowering (Anderson 2006). *Phacelia tanacetifolia*, also known as Lacy phacelia, is a native annual species found in areas throughout the southwestern United States and northern Mexico. This species can grow in both open areas and under shaded shrub canopies, typically growing during the spring. This plant can be distinguished by its blue flower and is widely used in the conservation of pollinators (Owayss et al. 2020). *Bromus rubens*, also known as red brome, is an exotic species of grass that invaded several regions of California over 100 years ago. This species is a winter annual grass typically found in the Mediterranean. Since its introduction to North America, this species has been able to take over areas relatively undisturbed, including The Mojave Desert, The Carrizo Plain National Monument, and The Sonoran (Salo 2005).

Purpose:

The purpose of this experiment is to determine if cooler temperatures, as seen under shrub canopies, could be used as an indicator for the germination success of both native and exotic plant species in the Carrizo Plain National Monument. This is important as native and exotic plant species can have different indirect effects on vertebrate animals in this ecosystem.

Hypothesis:

Temperature will act as a direct indicator for both native and exotic species germination, thus displaying each species' overall success both under shrub and in open conditions.

Predictions:

1) Higher temperatures will result in a lower germination rate of native plant species.
2) Invasive plant species will have a higher germination rate under all temperature conditions in comparison to California Native plant species.
3) Plant biomass will be greater at higher temperatures for both native and exotic plant species.
4) High soil moisture will increase both plant germination and biomass for both native and exotic plant species.

Methods:

Species

Design:

This experiment was conducted in a temperature-controlled facility where we tested the effects of various temperatures on the germination of 3 California Native plant species: *Salvia columbariae, Layia platyglossa, Phacelia tanacetifolia*, and 1 Invasive species of plant, *Bromus rubens*. 3 tables were set up with 70, 10cm diameter pots covering each table. Each table had 3 large heat lamps and 2 sets of UV lamps spread out to cover the table. Each set of heat lamps at each table contained either a 40, 60, or 100Watt light bulb, to allow for varying temperatures at each table. Each pot was filled with a 1:1 mixture of Organic Miracle Grow soil and Playground sand to best replicate the conditions found in arid California ecosystems (Figure 1). Once filled, 40 seeds of an individual plant species were added to the soil mixture. The number of seeds required was determined by taking the volume of each pot and determining the number of seeds required per cm^2 (Lortie et al. 2022). Each species was tested separately for the duration of 6 weeks, where after the soil was changed and the next species were planted. After planting, each pot received water once a week until appropriately saturated. 3 temperature loggers were placed randomly throughout each table to record the localized temperature and humidity at each location replicate. A total of 2 separate temperature loggers were placed away from the experiments to act as a control. Finally, the soil moisture of each pot was taken every 3 days as well as the current number of plants germinated.

Proposed Analysis:

GLMMS will be used to test the impact of temperature on both the overall germination and germination rate of both native and exotic species. Native and exotic species will be used as a factor to contrast the response of these species to potential temperature amelioration by shrubs. Field logger data collected at the Carrizo field site will be used to show that the experimental temperature effects mimic field conditions.

Figures:

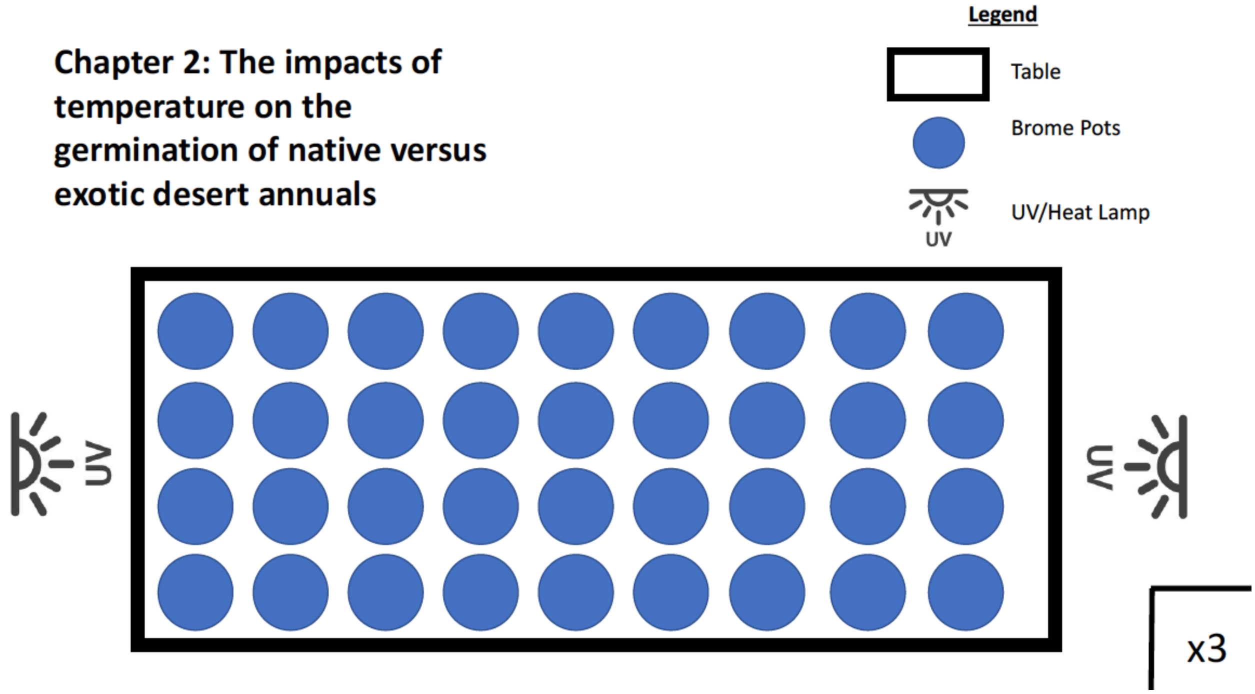

Figure 1: A rough schematic displaying the experimental design for the proposed experiment. A total of 3 tables were established with numerous pots containing native or exotic seeds. Each table consisted of heat lamps with varying light bulbs (40, 60 and 100Watts) to create a unique temperature for each table. The general location of both the Heat and UV lamps are shown to be on both sides of the tables and covered all pots.

Figure 2: An image displaying the set-up of the temperature trials for this project. The overall temperature increases from left to right. A total of 70 pots have been placed on each table with a total surface area of 78.5cm^2. Each table consists of 2 UV lamps (each with 3 adjustable heads) and 3 heat lamps positioned above the tables.

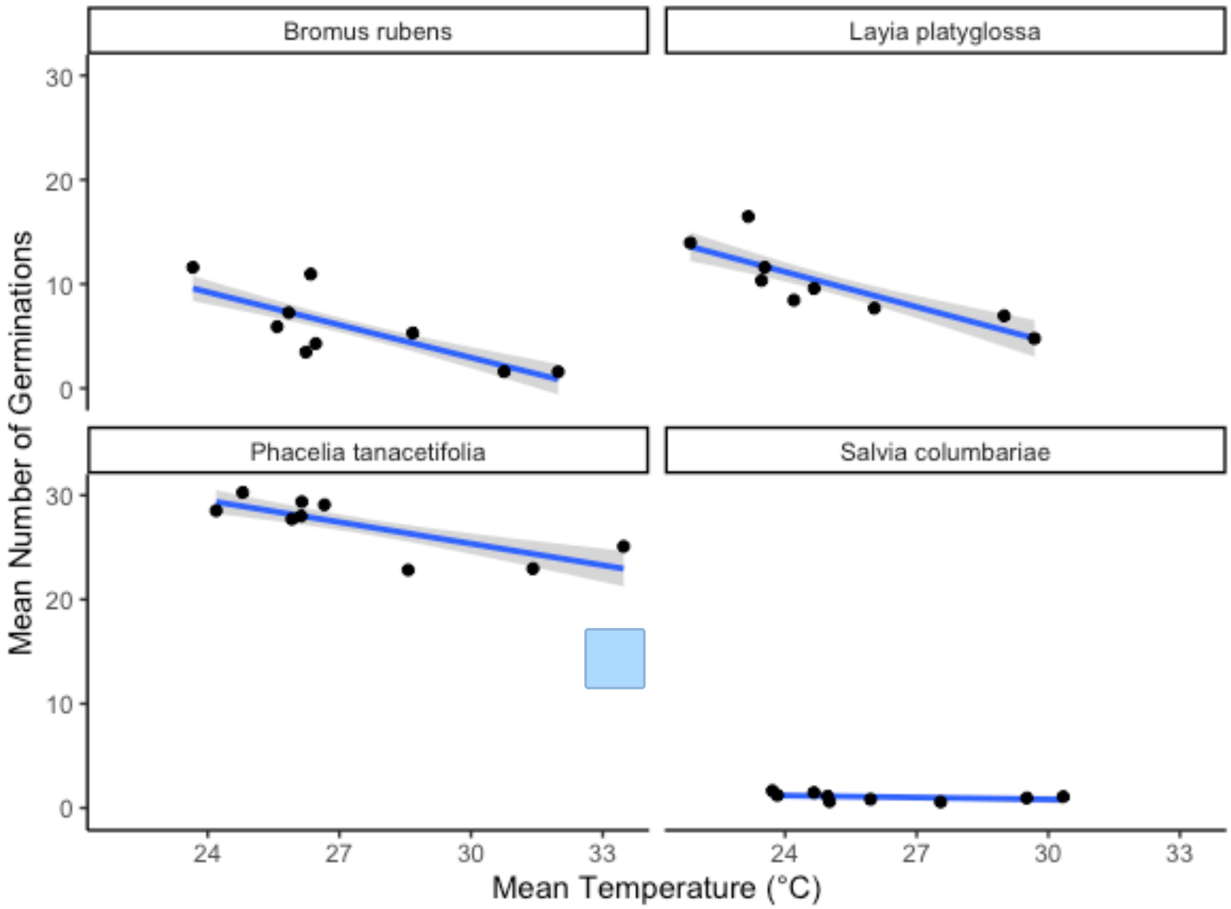

Figure 3: Mean germination of *Bromus rubens, Layia platyglossa, Phacelia tanacetifolia,* and *Salvia columbariae* against increasing temperatures (°C). Each trial was conducted separately and only one species was tested at a time. Standard error represented by a 95% shaded confidence interval.

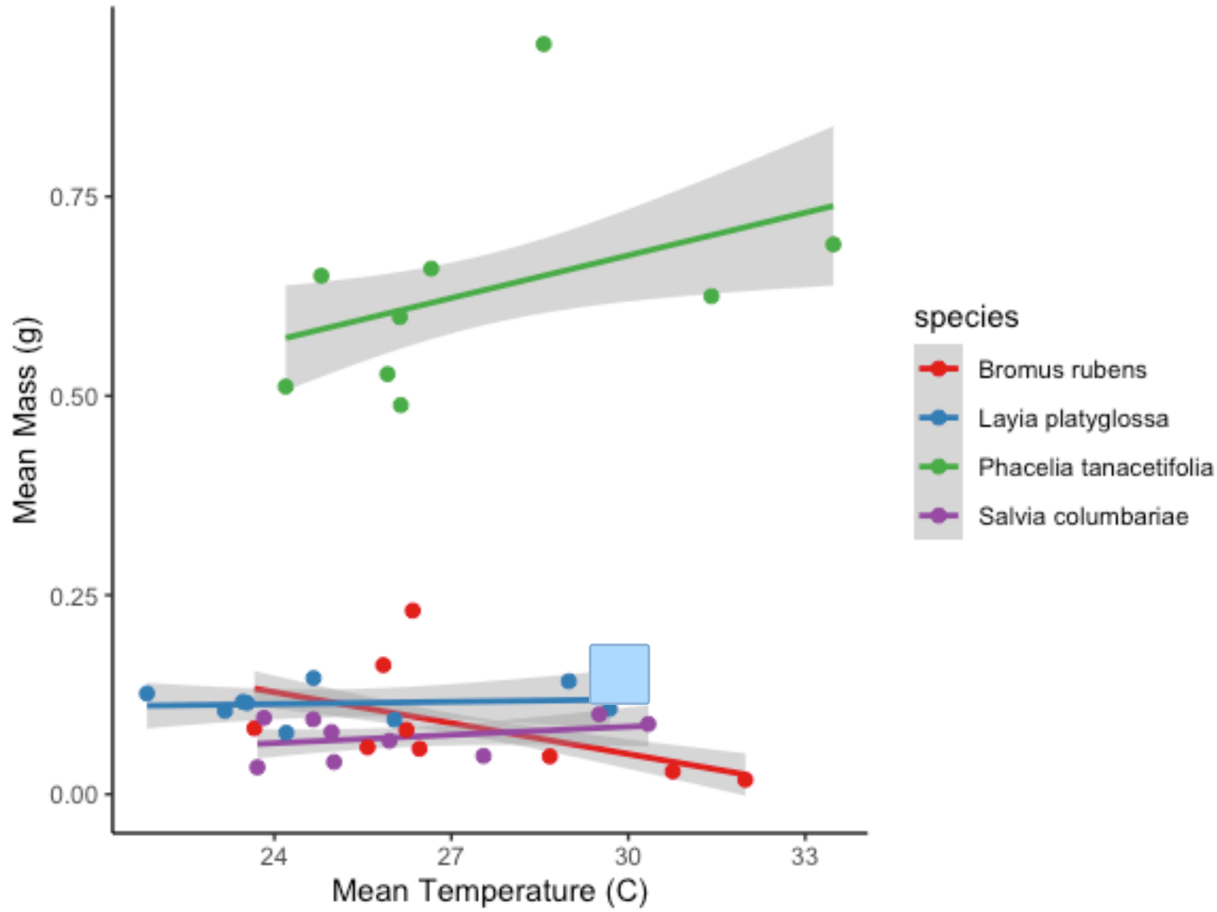

Figure 4: The relative effect of temperature on the mean mass of germinated plant individuals (g). All individuals within a pot were removed, dried, then weighed. Colored lines are specific to plant species with a shaded area showing a 95% confidence interval associated with the line of best fit.

Progress to Date:

The experiment has been completed as of the end of November 2021. Preliminary figures and statistics have been generated to display the findings of this experiment. We determined that temperature negatively impacts the germination of desert plant species ($p < 0.001$). This is true in terms of all tested individuals with the exception of *Salvia columbariae*.

Chapter 3: Shrub density effects on an endangered lizard of the Carrizo Plain National Monument, California

Purpose:

The purpose of this study was to test if the density of a foundation shrub species, *Ephedra californica* (Mormon tea), can be used to predict the presence of an endangered species of lizard, *G. sila*, in the Carrizo Plain National Monument, through the use of a combination of radio telemetry tracking and satellite imagery.

Hypothesis:

G. sila individuals benefit from the effects of increasing local shrub density and are thus likely more like to use these resource patches.

Predictions:

1) Shrub density and cover similarly predict G. sila resource use patterns within this ecosystem.
2) Shrub density is positively correlated with resource use by *G. sila*.
3) *G. sila* is more likely to be relocated aboveground than belowground with increasing shrub density at microsites.

Progress to Date:

We have geolocated all shrub individuals via google earth, combined the data with our 3-year radio telemetry dataset, and ground-truthed a subset of the satellite located shrubs. This data has been analyzed and figures have been generated along with their corresponding statistics. The manuscript has been completed, edited, and is currently under review at Ecosphere. The manuscript for this chapter has been provided separately from this document.

Chapter 4: The influence of high shrub density on local vertebrate association across varying ecosystems

Chapter Rational:

Several ecosystems within Southern California are classified as arid/semi-arid as they receive little to no annual rainfall and relatively high annual temperatures (Germano et al. 2011; Abella et al. 2012). In ecosystems where organisms experience high-stress abiotic conditions, competitive, or otherwise net negative interactions, are often reduced in favor of more positive interactions –this is also known as the Stress Gradient Hypothesis (Bertness & Callaway 1994). These net positive interactions occur between species, such as an animal reliant on shrubs to escape the harsh climate, increasing the likelihood of survival, while also influencing the overall community composition and structure (Ivey et al. 2020; Zuliani et al. 2021). While species, such as *Gambelia sila*, are known to use shrub cover to aid in thermoregulation (Ivey et al. 2020; Lortie et al. 2020) several other species directly interact with these shrubs in order to survive. Species such as *Dipdymus ingens*, the Giant Kangaroo Rat, and *Lepus californicus*, the Black-Tailed Jack Rabbit, utilize these shrubs not only for cooling but for foraging and protection from predation (Johnson & Anderson 1984; Prugh & Brashares, 2010). The association of several different species to these foundational shrubs will influence the overall community composition while influencing the net outcome of both direct and indirect interactions (Zuliani et al. 2021). However, considering that some of these ecosystems within Southern California are more arid than others, the influence these shrubs have on local animal communities may vary. Further understanding the importance of the direct interaction between these shrubs and local animal communities, across an increasing stress gradient, can provide insight into the local anima community composition and utilization of these shrubs.

Purpose:

The purpose of this chapter is to test if higher shrub densities correlate with the abundance of all vertebrate species across varying ecosystems.

Research Questions:

- Will local vertebrate species show a higher association with high-density areas or in no density areas?
- Is there significance in temperature between high-density sites and no density sites?
- With the varying temperatures across increasing stress ecosystems affect animal associations?

Hypothesis:

Community vertebrate abundance will increase with increasing local shrub densities in, as individuals rely on the positive interactions associated with these foundational shrubs.

Predictions:

1) Vertebrate species abundance will be higher in areas of high *Ephedra californica* density than in areas absent of these shrub individuals.
2) With increasing micro and meso climate data, vertebrate individuals will be seen more frequently associated with increasing shrub densities than open areas.
3) Higher stress ecosystems will have higher abundances of vertebrate species at high shrub density areas than lower stress ecosystems.

Methods:

Study Sites:

3 separate sites were used to conduction of this experiment. Cuyama (34.848726, -119.48312) acted as our relatively low-stress site. This area of California sits at an elevation of 848 meters above sea level, has an average temperature of 19˚C, and has an average annual precipitation of 45cm. The main shrub species that dominate this site is *Ephedra californica*. The Carrizo Plain National Monument (35.11982, -119.62853) was used as this experiment's medium stress site. This site sits at an elevation of 2697ft with an average temperature of 23˚C. The average precipitations of this site are about 25cm, however, this site goes through several months with minimal no rain. The study site is also dominated by the shrub *Ephedra californica* with several invasive grass species, including *Bromus rubens*. The final site used to display a high-stress environment was Tecopa, an area located within the Mojave Desert (35.851515, -116.18671). This site is also heavily dominated by the foundational shrub species *Ephedra californica*, with other shrub individuals such as *Larrea tridentata*. This area's annual precipitation can reach a low of 8.9cm and temperatures as high as 38˚C.

Study Species:

Similar to the previous projects, the main shrub species that was focused on in the experiment is *Ephedra californica*. This species is the dominant woody plant species in both the Panoche and the Carzzio field sites. This is a vital foundation species that could play a major role in the restoration of desert ecosystems in California (Lortie et al. 2018, Filazzola et al. 2018). This species is resilient and can survive large abiotic stressors, such as drought, extreme heat, and lack of nutrition, while also surviving mechanical damage, such as branch breaking or herbivory (Lortie et al. 2018). This species is particularly used by several species of vertebrates including the Blunt-Nosed Leopard Lizard (Noble et al 2016), Giant Kangaroo Rat (Prugh & Brashares, 2010), and San Joaquin Jack Rabbits.

Several vertebrate species are local to Cuyama, Carrizo National Monument, and Tecopa. Over the last few years, we have compiled a list of species we have seen both through camera trap data and visual observations. A total of 81 species have been observed and a list has been generated in the following github repo (https://github.com/cjlortie/California_desert_species/blob/gh-pages/data/animals.csv). These species, include the California Horned Lizard, Western Rattlesnake, Bobcats, Coyotes, and Kit Foxes, just to name a few.

One of the key species observed at these sites is *Dipodomys ingens*, or the Giant Kangaroo Rat. This is a small rodent species that are listed as Federally Endangered. This species is known for creating interconnecting burrows throughout these arid ecosystems (Prugh & Brashares, 2010). These species consume the seeds found underneath shrub canopies, resulting in them showing high associations to foundational shrub species.

One other species that are frequently observed through camera traps in these sites is *Lepus californicus*, otherwise known as the Black-Tailed Jack Rabbit. This species is frequently found both in the Carrizo and Cuyama, and is most frequently observed through camera traps. This species typically consumes vegetation both in open areas and under shrub canopies (Johnson & Anderson 1984).

Design:

This chapter was conducted in the Carrizo Plain National Monument, Cuyama Valley, and the Tecopa. Within each site 4, 20m radius high shrub density plots, ranging from 10-13 shrub individuals, were be established along with 4, 20m radius no shrub density plots (**Figure**

5). The 3 sites had a total of 24 plots to be established, 12 consisting of high shrub density and 12 consisting of no shrub density.

Camera Traps:

2 cameras, VIKERI Model A1, were placed at each plot (2 cameras x 24 plots = 48 camera traps deployed). Both of the cameras were stationed looking into its designated microsite and were placed at opposite ends. These cameras were angled to not directly face one another, reducing misfires caused by their individual activity. These traps remained at the site for the duration of the field season and receive regula[illegible]intenance every 3-4 days. Datasheets will consist of: date, rep, day, plot, density, animal presence, species (RTU), time block, actual time, behavior, and observations. Analysis of the data will be conducted to show the total number of hits in the areas that are classified based on the corresponding plot. Any photos of humans that coincidentally trigger the cameras will not be added and will be deleted.

Temperature Measurement:

Mesoclimate and relative humidity was recorded using a Mengshen hand-held humidity reader. In this experiment, we define mesoclimate as the climatic measures including temperature and humidity within a plot, whereas we define microclimate as the localized climatic data at a shrub or open microsite. This data was collected when the sites are initially established, maintained, and de-assembled. In addition, microclimate was recorded using OMEGA USB loggers, which were suspended above ground [illegible]oximately 20cm on a stake. 2 pendants were placed at each established plot. At high-densit[illegible]crosites, the loggers were placed under shrub canopy, while at no density microsites 2 loggers were placed in the open. These loggers remained within shrub and open microsites for the duration of the field experiment. Hourly temperatures were logged (°C) by pendants and used to calculate the daily mean and maxima.

Proposed Analysis:

All statistical analysis of this experiment will be conducted using the statistical program R. GLMs will be used to examine the relationship between high shrub density/no shrub density and vertebrate abundance. Mesohabitat and microhabitat temperature will be treated as covariates in the data. Comparison across ecosystems on shrub/open animal association will be conducted. Total vertebrate abundance will be[illegible]ted as a quasipoisson with animal presence as a binomial. In addition, ANOVAs with Chi-squared tests will be performed where variables in the model are shown to be significant. Tuckey tests will be used for post-hoc analysis of the GLMMs to test the interactions.

Schematics:

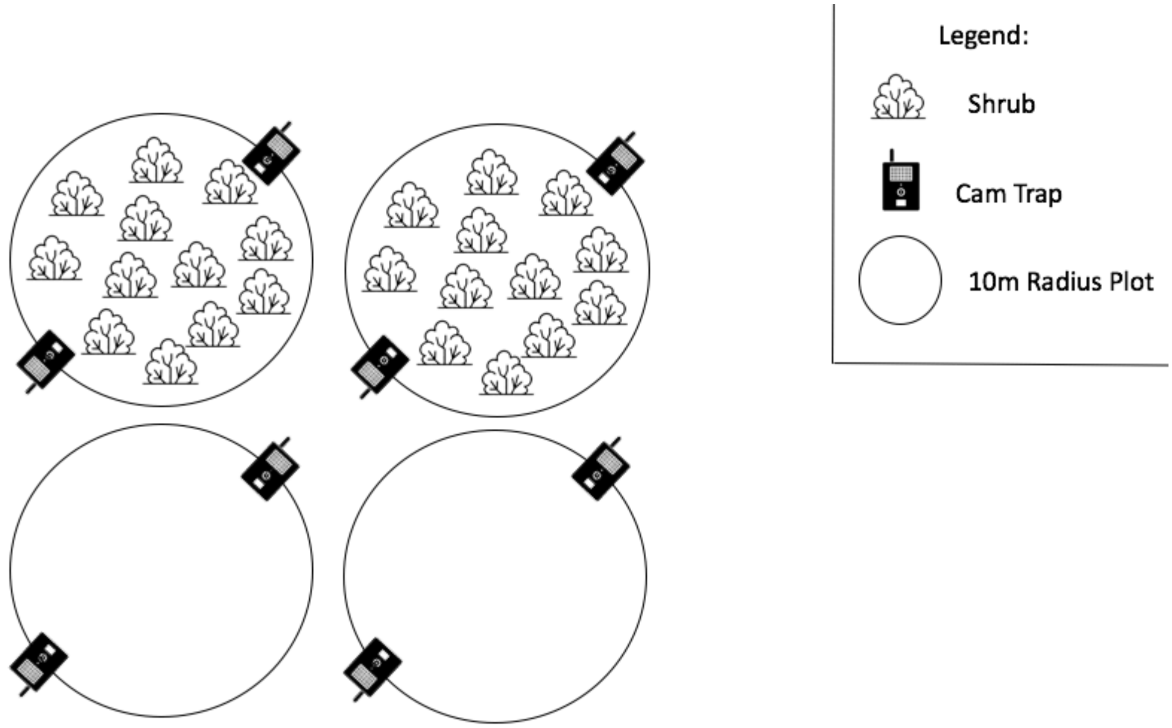

Figure 5: Schematic displaying the site establishment for project 4. A total of 24, 20m radius circular plots were established with 12 of these plots consisting of a high density of shrubs and 12 consisting of no shrubs. The general location of camera traps is also depicted and relates to each established plot.

Progress to Date:

This project was conducted this field season from May 2022 to early June 2022. All data has been collected for each established site. Camera trap data has been downloaded from the associated SD cards and is in the process of being processed for analysis. During the summer months of 2022, the camera trap data will be processed and then analyzed.

Chapter 5: The effect of shrub loss and introduction on animal community assembly

Chapter Rational:

This chapter further builds on this thesis by connecting the findings of all 4 previous chapters into a manipulative experiment. The ecosystems across Southern California, while considered arid/semi-arid, vary in overall intensity (Germano et al. 2011; Abella et al. 2012). Testing the effects of this shrub density across a gradient of ecosystems within Southern California can provide key insight into shrub-animal interactions, as well as determining the effects density has on community composition. The benefits both plant and animal species receive from interacting with foundational shrub species have been well reported in several facilitation studies (Lortie et al. 2016; Ivey et al. 2020; Ghazian et al. 2020; Zuliani et al. 2021). Previous work by Zuliani et al. (2021) showed that in areas of higher density, vertebrate abundance and richness were significantly higher, suggesting when more shrubs are present, animals are given more opportunities facilitative interactions (Zuliani et al. 2021). Grass matter underneath these shrub canopies is typically higher in abundance than in hotter open areas suggesting that the facilitative interactions are not exclusive to plant-animal interactions (Filazzola et al. 2018). By manipulating the density of foundational shrub species in this chapter we can determine if these facilitative interactions between local plant and animal species is dependent on the availability and likelihood of these events occurring.

Purpose:

The purpose of this chapter is to examine the density-dependent associations between vertebrate species and foundational shrub species after the systematic removal of shrub individuals. This is different from a landscape-level experiment, as individual shrubs will be removed and added to determine if shrub loss or addition is a factor in vertebrate association. Observable vertebrate species within the study site will be observed to determine their associations to these varying levels of foundational shrub density.

Research Questions:

- Will local vertebrate species respond to the reduction and removal of *Ephedra* individuals? If so to what extent?
- Will vertebrate species relocate to areas where removed shrubs are replanted? If so, then which vertebrate species?
- How will the complete removal of shrub individuals impact vertebrate species abundance and richness?

Hypothesis:

Vertebrate abundance will positively increase with increasing *Ephedra californica* densities, due to the positive interactions associated with this foundational shrub species.

Predictions:

1) Vertebrate species not previously present in areas absent *Ephedra* will display higher association with these new artificially established areas.
2) Vertebrate species abundance will be higher in areas with a high *Ephedra* density both in natural and artificial plots.
3) Vertebrate species richness will be higher in natural *Ephedra* plots.

4) Vertebrate species will prefer interacting with *Ephedra californica* individuals than in open areas and their composition will vary across shrub densities.
5) Vertebrate species will have a decreased association with artificially open plots.

Methods:

Study Sites:

The study sites for this project will be the same as Project 4. We will be focusing on a lower-stress ecosystem (Cuyama), medium stress ecosystem (The Carrizo Plain National Monument), and a high-stress ecosystem (The Heart of Mojave).

Study Species:

The study species for this project will be the same as Project 4. The target plant species for this chapter will be *Ephedra californica* as it is the dominant shrub species within the 3 Southern California sites.

Design:

This chapter will continue in the Carrizo Plain National Monument, Cuyama Valley, and the Heart of Mojave. In these sites, we will establish a total of 10, 20m radius circular plots. These plots will vary in total *Ephedra californica* density from 0 individuals (natural open plots) to around 10-11 (natural shrub plots). These plots will be denoted as "natural" plots. An additional 10, 20m radius circular plots will have their *Ephedra californica* densities altered through the systematic removal and transplantation of individuals (Holzapfel & Mahall 1999; Mahall et al. 2018). These removals create "artificial open" plots and the subsequently removed individuals will be transplanted into new locations creating "artificial shrub" plots. These new artificial shrub plots will resemble the natural shrub plots with a range from 2-12 *Ephedra californica* individuals. This will allow for a total of 20 plots established in the Carrizo Plain National Monument (**Figure 6**).

A brief side note, in the event that we are not given permission to remove shrub individuals from each site, we will construct shrub replicates to test the variation of vertebrate association to varying shrub densities. These shrub replicates will consist of a rebar center (acting as the trunk of the shrub) with cloth material wrapped around it to simulate shrub cover.

Camera Traps:

2 cameras will be placed at each plot (2 cameras x 20 plots = 40 camera traps deployed). Both of the cameras will be stationed looking into its designated microsite and will be placed at opposite sides. These cameras will be angled to not directly face one another to reduce misfires caused by their individual activity. These traps will remain at the site for the duration of the field season and receive regular maintenance every 3-4 days. Datasheets will consist of: date, rep, day, plot, density (corresponding to "pseudo shrub" density), animal presence, species (RTU), time block, actual time, behavior, and observations. From there, an analysis will be conducted to show the total number of hits in the areas that are classified based on the corresponding "artificial shrub" plot. Any photos of humans that coincidentally trigger the cameras will not be added and will be deleted.

Focal Observations:

The final portion of this chapter includes the conduction of several hours of focal observations. Several hours throughout the duration of the field season, researchers will monitor plots and observe associated vertebrate species. These observations will be conducted between 8:00 AM and 6:00 PM every 4-5 days at each established plot. This allows a better understanding of the total abundance of vertebrate species in the area, allows for the validation of camera trap triggers, and will aid in species validation and identification.

Temperature Measurement:

Local measures of ambient temperature will be recorded using OMEGA pendant loggers, which will be suspended above ground by approximately 20cm, on a stake. 2 pendants will be placed at each established plot, one located underneath a shrub canopy and another located in the open. These pendants will remain within shrubbed and open microsites for the duration of the field experiment. Hourly temperatures will be logged (°C) by pendants and used to calculate the daily mean and maxima.

Dry Matter and Vegetation Identification:

Dry matter is the measure of the total mass of varying grass and vegetation species in a given area (Bartolome 2002; Filazzola et al. 2017). Dry matter will be collected by placing a 20cm x 20cm square randomly at both shrub and open microsites at each shrub density plot. All grass within the indicated square will be removed entirely from the ground and weighed on a digital scale to determine the total mass of vegetation growing. This estimate will be done at each plot a total of six times per plot where three samples will be located under shrub canopies and three samples will be taken in the open. Plots that do not contain three shrubs within will have all possible shrubs sampled and open microsites. Before removal of dry matter local matter both underneath shrub canopies and in open areas will be identified, using California plant identification guides, and the overall abundance of each species will be recorded.

Proposed Analysis:

All statistical analyses of this experiment will be conducted using the statistical program R. GLMMs will be used to examine the relationship between shrub density and overall vertebrate abundance. Dry matter and temperature will be treated as covariates. Total vertebrate abundance will be treated as a quasipoisson with animal presence as a binomial. In addition, ANOVAs with Chi-squared tests will be performed where variables in the model are shown to be significant. Tuckey tests will be used for post-hoc analysis of the GLMMs to test the interactions.

Chapter 5 Schematics:

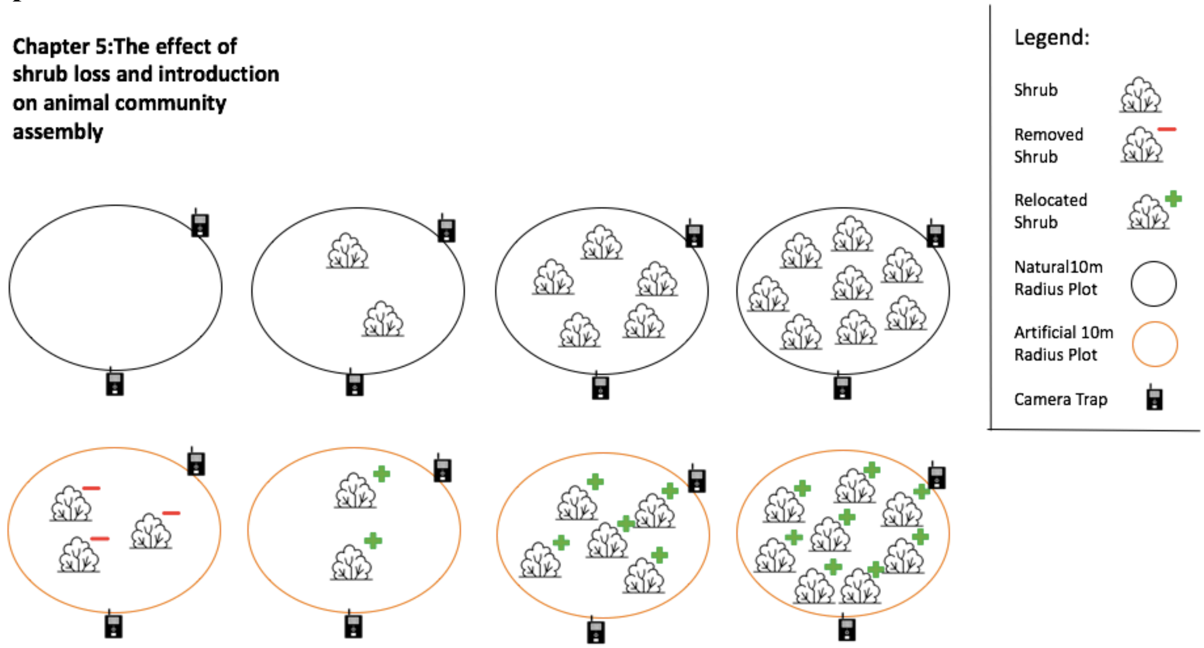

Figure 6: A rough schematic displaying this experiment's potential design. A total of 20, 20m radius circular plots will be established with a range of ephedra individuals located within each established plot. 10 of the established plots will be naturally established while 10 plots will have shrubs artificially planted. The general location of camera traps is also depicted and relates to each established plot.

Progress to Date:

We have decided to conduct this project during the upcoming 2023 field season from May to June 2023. All camera traps, pendants, and SD cards have been purchased and are ready for use. We are currently working on acquiring permits to conduct the shrub removal portion of the project. If this is not successful then shrub replicates we be deployed instead, as previously outlines in this project.

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