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# Paving the way for habitat disturbance: Different road types have distinct ecological impacts on annual plant communities and gall-forming insects in the Mojave Desert

Maria Carias[1], Emily Hascall[2], Kelsey Pennington[1], Jasmine Summers-Evans [2]

[1]University of California, Los Angeles; [2]University of California, Santa Barbara

Road disturbance can facilitate the establishment and growth of invasive plant species and herbivorous insects in adjacent ecosystems. The hydrological and atmospheric impacts of roads are especially important to understand in arid desert environments that are highly sensitive to water stress and dust pollution. In this study, we looked at how impacts of road disturbance change among different road types within the Mojave Desert. Specifically, we observed how three types of roads (paved road, dirt road, and hiking trail) and proximity to the roads impact both the abundance and size of germinating annual plants and the density of galls on creosote bushes (*Larrea tridentata*). Additionally, we tested the effect of dust pollution on the growth of *Erodium cicutarium* and *Bromus* spp. Different types of roads produced distinct ecological impacts on the surrounding plant and insect communities. Paved roads had the highest gall density and largest *Bromus* spp., while dirt roads had smaller *Erodium cicutarium*. Our findings contribute to the growing knowledgebase of how road disturbances uniquely impact plant invasion patterns and herbivorous insects.

Keywords: road disturbance, Mojave Desert, *Larrea tridentata*, *Erodium cicutarium*, *Bromus* spp.

## INTRODUCTION

Anthropogenic transportation corridors create habitat disturbances and fragmentation in surrounding environments (Coffin 2007). In 1998, the term “road ecology” emerged to refer to the science of how transportation corridors such as highways and roads affect ecosystem components, processes, and structures (Coffin 2007). Since then, the subject of transportation infrastructure and its effects on ecosystems has become more widely studied. Roads have been shown to affect both the abiotic and biotic components of landscapes by altering factors such as hydrology, dust pollution, microclimate conditions, soil erosion, and animal mortality. Transportation corridors can also serve as conduits for plant and animal movement and are often cited as major causal factors in the successful invasion of non-native flora and fauna to adjacent landscapes (Coffin 2007). Species that benefit from corridor facilitation are typically generalist species that are able to exploit highly variable environmental conditions (Forman and Alexander 1998). The construction and maintenance of roads can also remove native species and their seed banks, making it difficult for them to reestablish after disturbance (Holzapfel and Schmidt 1990). Understanding how disturbances caused by roads impact the ecology of surrounding biotic communities is crucial for better informing transportation land-use decisions (Dix et al. 2010).

While ecosystem-level impacts of transportation corridors on adjacent environments are well understood, less is known about how non-native plant and herbivorous insect communities respond to different road designs. Different types of roads vary in their level of environmental disturbance (Holzapfel and Schmidt 1990). Paved roads pose the most ecological impact on nearby ecosystems, followed by unpaved roads and walking trails (Holzapfel and Schmidt 1990). Paved roads are designed to drain water from their edges, which can increase the moisture available to adjacent plant communities (Holzapfel and Schmidt 1990). Higher water availability coupled with additional disturbances can increase an environment's vulnerability to non-native plant invasions and insect parasitism. According to the Plant Vigor Hypothesis, insect herbivores prefer to oviposit on large, vigorously growing plants (Price 1991). Therefore, insect herbivores are generally drawn to less water-stressed plants, which are often found along roadsides.

In addition to changes in hydrology, roads can alter atmospheric composition in adjacent microhabitats (Coffin 2007). Air tends to be dustier near roads, especially at unpaved dirt roads. As roads are constructed and surrounding soils are eroded, dust pollution is more easily spread to nearby plants. The coating of dust can impede vegetation's ability to photosynthesize, which can hinder the growth and vigor of roadside plants (Farmer 1993). Such impact can lead to less favorable conditions for native plant communities, compounding the negative effects of road-induced hydrological changes. At the same time, less vigorous plants are also less desirable to herbivorous insects (Cornelissen et al. 2008). These two disturbance factors can uniquely alter surrounding plant and insect communities.

The hydrological and atmospheric impacts of transportation corridors are especially important to understand in arid desert ecosystems that are highly sensitive to water stress and dust pollution. Plant succession and insect responses following disturbance are less understood in arid landscapes relative to temperate regions (Abella 2010). In the Mojave Desert, the spread of non-native annual plants and the distribution of herbivorous insects are of particular concern. Previous studies in the Mojave Desert have found the richness and biomass of non-native annual plants increase with dirt road density (Brooks and Berry 2006). The invasion of non-native plant species is a primary cause of biodiversity decline and threatens the existence of native plants and their associated organisms (Barbosa et al. 2010). Non-native annual grasses can also increase the fire load of an environment, making ecosystems like the Mojave Desert increasingly flammable and vulnerable to wildfires (Kalwij et al. 2008). Since roads can function as corridors for parasitism and disease spread as well, herbivorous insects such as gall-forming insects can serve as key indicators of parasitic responses to disturbance (Lightfoot and Whitford 1991). Galls are abnormal plant tissue growth produced in response to injected chemical stimuli of invading organisms (Russo 2006).

Though the complex chemical relationships between host plants and gall-forming insects vary greatly by species, there is growing evidence that galls redirect nutrients from their host plant's roots and leaves into gall tissues, forming nutrient sinks for the host plants. The management of non-native plants and parasitic insect species is hampered by a lack of information on desert ecosystems, making the Mojave Desert an ideal location to further investigate the negative effects of road disturbances (Brooks and Berry 2006).

In this study, we explored how annual plant species composition and regional gall density differ in areas near and far from different types of desert roads. We studied three road types: a paved one-lane expressway, a dirt vehicle road, and a dirt hiking trail. We focused on two dominant non-native plants in the Mojave Desert—*Erodium cicutarium* and *Bromus* spp.—due to their pervasiveness in the region (Brooks and Berry 2006). We asked how road type and proximity to a road would affect the abundance and size of *Erodium cicutarium* and *Bromus* plants, the abundance of native annual plants, and the density of gall parasitism. To assess gall density, we studied creosote bushes (*Larrea tridentata*), which are critical host plants for gall-forming midge flies (Cecidomyiidae) and their parasites. Creosote bushes are hosts to at least 16 species of gall midges, all from the genus *Asphondylia* (Russo 2006). Roadside creosote shrubs tend to be larger and have denser foliage, as well as higher arthropod density (Lightfoot and Whitford 1991). As predicted by the Plant Vigor Hypothesis, the quantity of water availability has shown to be a large determinant in the ability of a host plant to support gall midges, yet there are large variations among host plant species that are still widely unknown (Russo 2006).

We hypothesized that areas closer to roads would have a higher abundance of non-native annual plant species, larger non-native annual plants, fewer native annual plants, and a higher density of galls. We also hypothesized that the paved road would display the largest non-native plants and the highest density of galls compared to the dirt road and trail. Since paved roads typically funnel higher amounts of water to surrounding landscapes (Holzapfel and Schmidt 1990), we expected surrounding non-native plant and pest communities to benefit the most near the paved road compared to the other road types. We expected dust pollution to be higher on the dirt road than on the trail and paved road, causing plant abundance and gall density to be lowest at that site. Lastly, we expected native plant species abundance to be highest at the trail road since it is the least disturbed area. We hoped answering these questions would provide ecologists and those involved in road construction management with vital information on how impacts of road disturbance on the surrounding plant and insect communities change between road designs.

## METHODS

### *2.1 Study System*

We conducted our research between February 24 and February 28, 2021, during the germination period of annual plants in the Mojave Desert. Research was done at the Sweeney Granite Mountains Desert Research Center (hereafter referred to as "the Granites"), a field station owned by the

University of California, Riverside. The Granites is located in the East Mojave Desert in San Bernardino County and lies within the Mojave National Preserve. Near the center's eastern boundary, the topography descends from high ridges into bajadas and washes densely vegetated by multiple habitat types (James Andre, Sweeney Granite Mountains Desert Research Center). The washes support creosote bush scrub and mixed desert scrub communities (Simpson et al. 1997). The landscape cover also supports an abundant annual plant community, including both native and non-native species such as *Erodium cicutarium* and *Bromus* spp.—which likely include a mix of *Bromus madritensis* and *Bromus tectorum.*

We collected data from paved, dirt, and trail roads. The paved road site was located at Kelbaker Road, a one-lane expressway west of the Granites research facility. Kelbaker Road was first developed as a dirt road in the 1930s. The road was paved in 1988 and repaved in 2018 (Pers. Comm. James Andre). The dirt road site was located along a 1.1-mile-long vehicle road stretching between Kelbaker Road and the Granites research facility. The road was first developed in the 1950s but has seen a dramatic increase in use over the past 15 years, as it provides access to campsites alongside the road. The trail site was located along the Al A. Allanson trail within the boundary of the Granites research facility. The trail was built in 2001, but the first 100 meters of the trail dates back to the 1930s as a portion of a previous two-track road historically used by ranchers.

To disentangle road disturbance from other numerous geographical or biological factors, we looked at two zones within each road site: near and far from the road. The near zone included plants within three meters of the edge of the road and the far zone included plants at least 10 meters away from the edge of the road. Within each zone at each site, we conducted multiple surveys regarding the surrounding annual plant and gall communities.

*2.2 Plant Surveys*

In order to determine how different types of roads distinctively serve as corridors for invasive species, we surveyed annual plant abundance and size within a 0.5 $m^2$ quadrat. We quantified the most common non-native annual species, *Erodium cicutarium* and *Bromus*, as well as all native annual plants we encountered. For abundance, every *Erodium cicutarium*, *Bromus*, and native annual was counted. For size, five *Erodium cicutarium* and five *Bromus* were randomly selected for measurement. To measure *Erodium cicutarium,* we used the length between the two longest leaves. For *Bromus*, we pulled the single grass strand straight and measured from base to tip.

To account for possible differences in size of germinating annuals based on their location either inside or outside the canopy cover of surrounding bushes (Holzapfel and Mahall 1999), we replicated all plant surveys both inside and outside the canopy cover of creosote. To do so, we placed the quadrat inside the canopy cover, with the edge of the quadrat aligning with the bush's longest branch. We then flipped the quadrat so it lay outside the canopy cover with the same edge still aligning with the longest branch of the bush.

*2.2 Gall Survey*

To assess how different types of roads distinctively serve as corridors for insects, we conducted surveys on gall density in creosote bushes. Creosote bushes were systematically selected by surveying the next available bush within our designated near and far zones at each of our three road types. To account for possible geographical differences between the left and right sides of the roads, we surveyed bushes on both sides. To account for size differences between creosote bushes, we took measurements for the volume of an ovoid – as it best represented the shape of an average creosote within our survey parameters. A transect tape was used to measure the bush's longest radius, shortest radius, and height of tallest branch. Galls were counted within each bush, identifying and enumerating between species types. Binoculars aided in counting galls on tall, unreachable branches.

*2.2 Experimental Plot*

To assess the effect of dust pollution on the growth rate of germinating non-native annuals, we conducted a sub-experiment on both *Erodium cicutarium* and *Bromus* from February 24–28, 2021, that measured how growth rate differed given different frequencies of dusting. The experiment included three different 1 $m^2$ plots located at the Granites research facilities away from any road disturbances. In each of the three plots, 25 *Erodium cicutarium* and 25 *Bromus* were randomly selected to receive the dusting treatments.

We dusted each plot's plant replicates at different frequencies. Plot 1 served as our control group and was left undusted. Plot 2 was dusted only once at 10:00 A.M. on February 24. Plot 3 was dusted every morning at 10:00 A.M. for each of the five days of our experiment. An equal amount of dust was administered between the two experimental plots, leaving the number of times dusted as our only variable. To standardize the amount of dust used within each plot, every *Erodium cicutarium* replicate was sprinkled with dust until it was visibly completely covered. Every *Bromus* was sprinkled with 1 tablespoon of dust. The dust used in the study was collected dirt found directly outside the plot (void of any rocks, debris, or other plant material).

Each plant replicate was initially measured at the start of our experiment on February 24 at 9:00 A.M. and remeasured at the end of the experiment on February 28 at 5:00 P.M. Initial measurements were subtracted from final measurements to calculate the growth of every plant replicate across the five days.

**STATISTICAL ANALYSES**

All statistical analyses were done using JMP Pro 15 statistical software, (JMP®, Version < *Pro 15*>. SAS Institute Inc., Cary, NC, 1989-2019).

*3.1 Plant Survey Analyses*

A Two-Way ANOVA was used for all plant surveys. To account for variation among individual creosote bushes, creosote ID number was nested as a random effect. To see how *Erodium cicutarium* and *Bromus* spp. abundance differed, we analyzed abundance across the three different roads, the distance from the road, and the interaction between road type and road distance. To assess how *Erodium cicutarium* and *Bromus* sizes differed, we analyzed size across each road type, the distance from the road, and the interaction between road type and road distance.

A One-Way ANOVA was used for all experimental plots. To measure how *Erodium cicutarium* growth differed between the experimental plots, we analyzed growth across all three plots. The same test was performed for *Bromus* across all three plots.

*3.2 Gall Survey Analyses*

To account for size differences between creosote bushes when looking at galls, we used gall abundance to calculate gall density within each cubic meter of a creosote bush. First, we calculated the volume of each bush replicate by using the formula for volume of an ovoid, (4/3 * longest radius * shortest radius * height). Creosote volume data was log transformed to meet the constraint of normality. Gall abundance was divided by our transformed creosote volume to estimate gall density. Gall density data was also log transformed for normality.

A Two-way ANOVA was used for all gall surveys. To assess the response of gall density to different road types, we analyzed road type, road distance, and the interaction between road type and road distance.

**RESULTS**

*4.1 Plant Surveys*

*Erodium cicutarium* abundance did not differ among road types (N = 102, F = 1.87, p = 0.16, Fig. 1), between distance from road (N = 68, F = 0.017, p = 0.90, Fig. 1), and there was no interaction effect between road type and distance from road (N = 34, F = 2.80, p = 0.065). *Bromus* spp. abundance was lowest at dirt roads (N = 68, F = 6.42, p = 0.0024, Fig. 2). *Bromus* did not differ in abundance between near and far zones (N = 102, F = 1.73, p = 0.19, Fig. 2), and there was no interaction between road type and road distance (N = 34, F = 2.87, p = 0.062). Native annual abundance was higher near trails (N = 68, F = 12.65, p = <0.0001, Fig. 3). Native annual abundance did not differ between near and far zones (N = 102, F = 0.84, p = 0.36, Fig. 3) and there was no interaction between road type and road distance (N = 34, F = 0.62, p = 0.54).

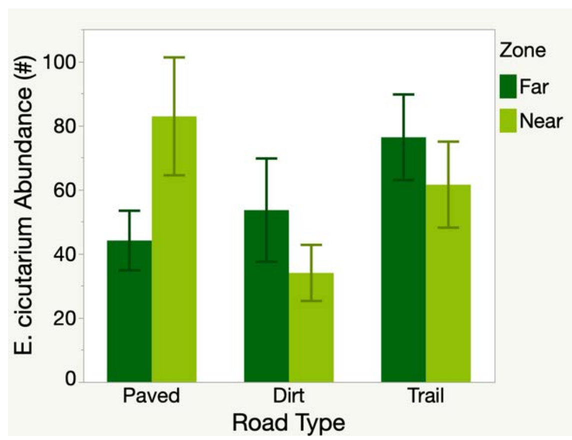


**Figure 1. The effect of road type on *Erodium cicutarium* abundance.** We counted *Erodium cicutarium* abundance near creosote bushes by three different types of roads in the Mojave Desert—a paved one-lane expressway, a dirt vehicle road, and a hiking trail. Surveys were conducted both near (within 3 m of the road) and far (at least 10 m away) from the roads. *Erodium cicutarium* abundance did not differ among road types (N = 102, F = 1.87, p = 0.16) or by distance from road (N = 68, F = 0.017, p = 0.90). There was no interaction effect between road type and distance from road (N = 34, F = 2.80, p = 0.065)

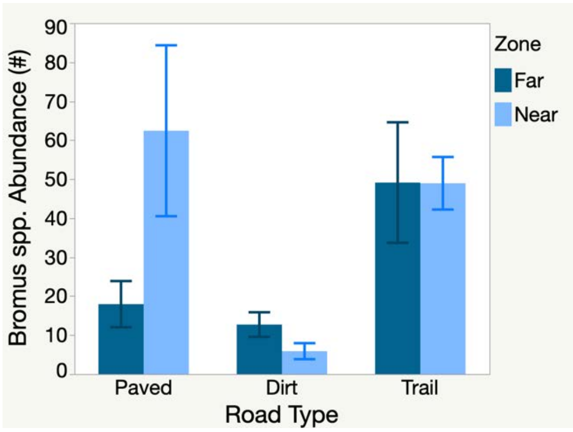


**Figure 2: The effect of road type on *Bromus* spp. abundance.** We counted *Bromus* abundance near creosote bushes by three different types of roads in the Mojave Desert—a paved one-lane expressway, a dirt vehicle road, and a hiking trail. Surveys were conducted both near (within 3 m of the road) and far (at least 10 m away) from the roads. The abundance of *Bromus* was lowest at dirt roads (N = 68, F = 6.42, p = 0.0024) but abundance did not differ between near and far zones (N = 102, F = 1.73, p = 0.19). There was no interaction between road type and road distance (N = 34, F = 2.87, p = 0.062).

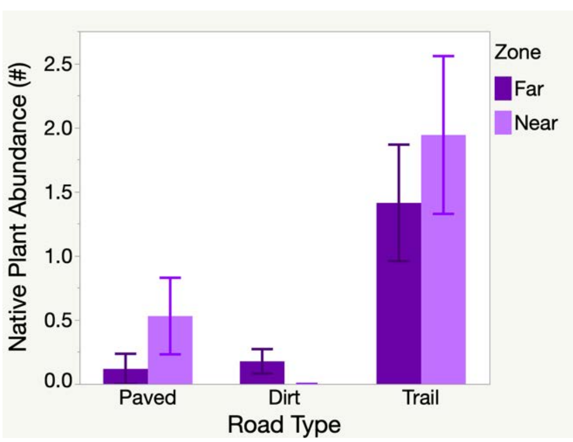


**Figure 3. The effect of road type on annual native plant abundance.** To assess how road types affect native plant establishment, we collected native plant abundance across three different road types- a paved one-way express lane, a dirt vehicle road, and a hiking trail. Surveys were conducted both near (within 3 m of the road) and far (at least 10 m away) from the roads. The abundance of native annuals was higher near trails (N = 68, F = 12.65, p = <0.0001). Abundance also did not differ between near and far zones (N = 102, F = 0.84, p = 0.36) and there was no interaction between road type and road distance (N = 34, F = 0.62, p = 0.54).

*Erodium cicutarium* size was smallest at dirt roads, (N = 340, F = 8.92, p = 0.0003, Fig. 4) larger near roads (N = 510, F = 191.64, p = <0.0001, Fig. 4), and there was an interaction between road type and road distance (N = 70, F = 3.16, p = 0.047). *Bromus* size was larger at paved roads when compared to trails only (N = 340, F = 4.38, p = 0.014, Fig. 5) and larger near roads in general (N = 510, F = 8.73, p = 0.0039, Fig. 5). There was no interaction between site and zone (N = 70, F = 2.32, p = 0.10).

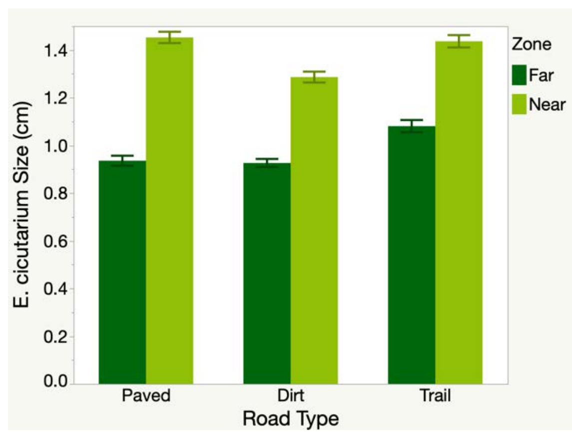


**Figure 4. The effect of road type on *Erodium cicutarium* size.** We measured the size of *Erodium cicutarium* near creosote bushes by three different types of roads in the Mojave Desert—a paved one-lane expressway, a dirt vehicle road, and a hiking trail. Surveys were conducted both near (within 3 m of the road) and far (at least 10 m away) from the roads. The size of *Erodium cicutarium* was smallest at dirt roads (N = 340, F = 8.92, p = 0.0003), larger near roads (N = 510, F = 191.64, p = <0.0001), and there was an interaction between road type and road distance (N = 70, F = 3.16, p = 0.047).

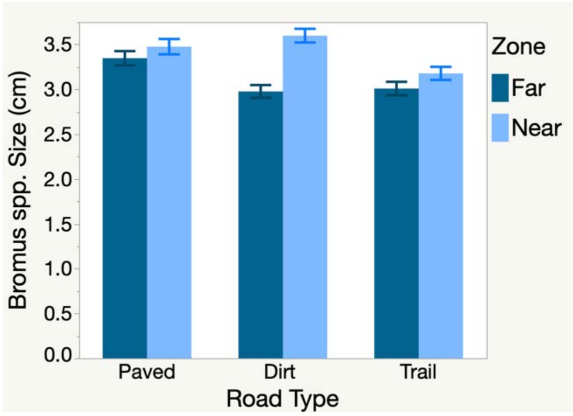


**Figure 5. The effect of road type on *Bromus* spp. size.** We measured the size of *Bromus* spp. near creosote bushes by three different types of roads in the Mojave Desert—a paved one-lane expressway, a dirt vehicle road, and a hiking trail. Surveys were conducted both near (within 3 m of the road) and far (at least 10 m away) from the roads. *Bromus* size was larger at paved roads when compared to trails only (N = 340, F = 4.38, p = 0.014) and larger near roads in general (N = 510, F = 8.73, p = 0.0039). There was no interaction between site and zone (N = 70, F = 2.32, p = 0.10).

### *4.2 Gall Surveys*

Within 144 creosote bushes, we counted 2,117 galls belonging to four main species—493 *Asphondylia resinosa* galls, 1,047 *Asphondylia auripala* galls, 210 *Asphondylia clavata* galls, and 351 *Asphondylia foliosa* galls (Table 1, Table 2).

**Table 1. Total number of galls of each species found per road type.** Within 144 creosote bushes, we counted 2,101 galls belonging to four main species of gall midges. The most abundant species was *Asphondylia resinosa,* accounting for 49.8% of total galls.

| | ROAD TYPE | | | |
|---|---|---|---|---|
| GALL SPECIES | DIRT | PAVED | TRAIL | **TOTAL** |
| *A. auripala* | 74 | 250 | 169 | **493** |
| *A. clavata* | 10 | 73 | 127 | **210** |
| *A. foliosa* | 52 | 156 | 143 | **351** |
| *A. resinosa* | 295 | 485 | 267 | **1,047** |
| **TOTAL** | **431** | **964** | **706** | **2,101** |

**Table 2. Total number of galls of each species found per zone.** Within 144 creosote bushes surveyed, 70% of all total galls counted were found in creosote bushes less than three meters from roads.

| | **ZONE** | | |
|---|---|---|---|
| GALL SPECIES | NEAR | FAR | **TOTAL** |
| *A. auripala* | 319 | 174 | **493** |
| *A. clavata* | 156 | 54 | **210** |
| *A. foliosa* | 278 | 73 | **351** |
| *A. resinosa* | 717 | 330 | **1,047** |
| **TOTAL** | **1,470** | **631** | **2,101** |

Overall gall density was higher at paved roads (N = 48, F = 4.38, p = 0.014, Fig. 6) and near the roads (N = 72, F = 20.36, p = <0.0001, Fig. 6). There was no interactive effect of road type nor distance from road on gall density (N = 24, F = 0.78, p = 0.46).

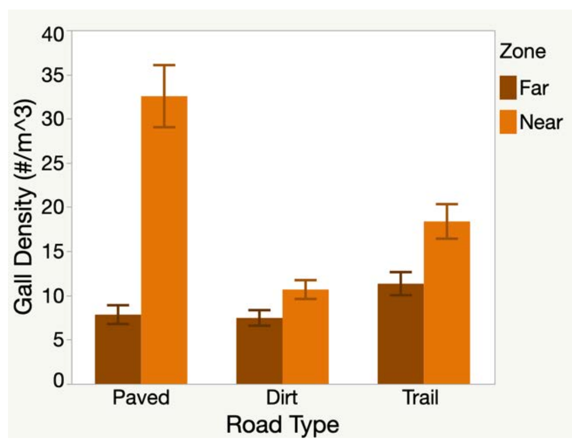


**Figure 6. The effect of road type on gall density.** We counted gall density on creosote bushes across three different types of roads in the Mojave Desert—a paved one-lane expressway, a dirt vehicle road, and a hiking trail. Gall abundance surveys were done both near the roads (within 3 m of the road), and far (at least 10 m away) from the roads. Gall density was highest at paved roads (N = 48, F = 4.38, p = 0.014) and near roads (N = 72, F = 20.36, p = <0.0001). There was no interactive effect of road type nor distance from road on gall density (N = 24, F = 0.78, p = 0.46).

*4.3 Experimental Plots*

*Erodium cicutarium* grew the most in the plot that was dusted only once (N = 25, F = 17.36, p = <0.0001, Fig. 7), while *Bromus* grew the most in the plot that was not dusted at all (N = 25, F = 19.05, p = <0.0001, Fig. 7).

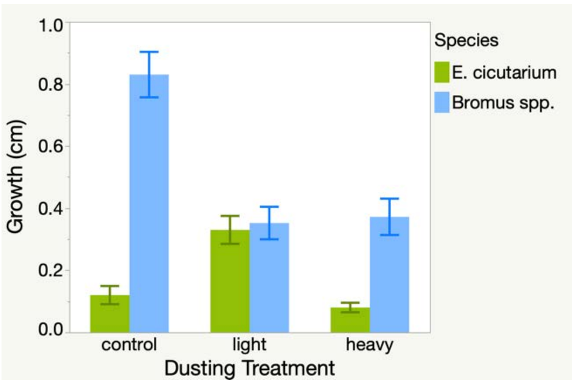


**Figure 7. The effect of dust on *Bromus* spp. and *Erodium cicutarium* growth.** We set up three experimental plots at the Sweeney Granite Mountains Research Center located in the Mojave Desert. Within each plot, we randomly selected 25 plant replicates of both *Bromus* and *Erodium cicutarium*. Each plot received a different dusting treatment across five days: the 'control' plot was not dusted, the 'light' plot was dusted only once during the first day, and the 'heavy' plot was dusted daily. To measure growth, initial size measurements were taken and compared with size measurements after the five days. *Bromus* grew the most in the control plot (N = 25, F = 19.05, p = <0.0001), and *Erodium cicutarium* grew the most in the light plot (N = 25, F = 17.36, p = <0.0001).

## DISCUSSION

*5.1 Annual Plant Abundance and Size*

As expected, road type influenced abundance and size of invasive annual plants. Road proximity did not influence the capacity for *Bromus* to grow, but the varying disturbances among the different types of roads influence the rate at which it can grow. We speculate its resilient nature initially allows *Bromus* to become uniformly established across a landscape, which explains why abundance does not seem to change closer to roads. However, with prolonged water stress, paved roads may support higher growth rates of *Bromus* than trails due to higher levels of water runoff. We reason we found the smallest abundance of *Bromus* near dirt roads because they cause the most dust to be kicked up onto the adjacent plant communities and are therefore not conducive to *Bromus* establishment. Another disturbance factor that can facilitate the establishment of *Bromus* is disrupted biological soil crust (Chambers et al. 2016). Soil crust can inhibit the germination and spread of *Bromus*, especially in areas of high disturbance. The construction, maintenance, and usage frequency of paved roads poses greater destruction to surrounding soil crust, potentially allowing *Bromus* to grow in greater abundance near paved roads compared to dirt roads and trails.

Previous studies have shown *Erodium cicutarium* is a generalist species, meaning it is resistant to drought and low levels of disturbance (Kimball et al. 2014). The resilient nature of *Erodium cicutarium* supports our finding that abundance did not change across different road types. Though its ability to establish was not influenced by roads, our finding that its size was higher in the zones near paved roads and trails, as well as in the lightly dusted experimental plots, leads us to believe *Erodium cicutarium* was able to thrive under conditions of light disturbance.

High levels of disturbance can be detrimental to native species and destroy seed banks (Holzapfel and Schmidt 1990). As expected, the road type with the lowest level of disturbance supported the highest abundance of native annual species. This finding shows how different road types not only influence non-native plant species but also impact the success of native species.

*5.2 Gall Density*

Higher water availability from runoff can produce more vigorous creosote bushes that would attract more gall-forming insects (Ludwig and Blanche 2001). Creosote bushes have been observed to have faster vegetative growth rates and higher leaf production when provided additional water (Sharifi et al. 1988). We observed larger, more vigorous creosote bushes near our road sites, which aligns with prior research on the correlation between water availability and creosote health. Our findings that gall density was highest near roads in general and especially high near paved roads was consistent with our hypothesis that road disturbance facilitates a higher density of gall-forming insects.

*5.3 Future Research*

Due to the timing of our study, we were only able to observe annual plants that had begun germinating a few weeks prior. A longer-term observational study on annual plants could provide additional insight into factors that affect non-native annual plant abundance and growth near desert roads. A previous study conducted on the effects of predation and competition on survivorship and community structure of desert annuals in the Sonoran Desert found that competition among annual plants reduced species' biomass and growth rates (Inouye et al. 1980). As the density of *Erodium* spp. decreased due to rodent predation, other annual species were able to increase in abundance across the landscape. Specifically, it would be interesting to assess if *Erodium cicutarium* and *Bromus* experience interspecific competition that alters their distribution and survivorship over the course of their lifespan.

According to the Plant Vigor Hypothesis, insect herbivores such as gall-forming midges may prefer plants that are less water stressed (Price 1991). Thus, creosote bushes already parasitized by other species known to increase water stress on plants (Sangüesa-Barreda et al. 2013)—such as mistletoe (*Viscum album)*—could exhibit less gall density compared to creosote bushes not already parasitized by mistletoe, especially when mistletoe increases water stress on plants. Within our gall survey, we observed three different occurrences of mistletoe, but there were not enough replicates to see any trends in regard to how mistletoe parasitism impacted gall abundance. Based on our study results, we speculate creosote bushes parasitized by mistletoe may not be as impacted from road disturbance as non-mistletoe parasitized creosote would be, and that mistletoe parasitism on creosote bushes may produce the greatest impact along paved roads compared to other road types. This would be important to further investigate how roads impact the surrounding plant communities within the Mojave Desert.

*5.4 Conclusion*

Overall, this study contributes to the growing literature on how different road designs impact the ecology of surrounding plant and animal communities within the Mojave Desert—specifically non-native plant species and gall-forming midges. Our findings suggest road disturbances are facilitating higher success of non-native annual plants. These non-native annuals could potentially be outcompeting native plants, which could be a cause for concern if it leads to state shifts within such a fragile desert ecosystem (Sheffer et al. 2001). Additionally, our findings displayed increased gall density due to road disturbance, specifically along paved roads. Though gall midges are native species, an increase in gall density may serve as a proxy for disease invasion. This raises concern for the negative health implications of plant hosts within the Mojave Desert (Russo 2006). Within the Mojave Desert, our study provides information that could be helpful to conservation efforts of road disturbance impacts on the surrounding plant communities, especially when making decisions on road design.

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