Invasive Plant Species Interactions

by

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Abstract

Biodiversity around the world has been declining, and one of the major contributors of its decline are invasive species. Invasive species can rapidly spread, and have disproportionate effects on communities, but it is relatively unknown how interactions between two or more invasive species in the same environment may affect each other or their environment. Using data from a paper by Adler et al (2018), different interactions between invasive/invasive, native/native, and native/invasive, were measured and compared, and the results used in creating a future greenhouse study for observing invasive biodiversity using growth and populations. It was found that invasive/invasive interactions were the least competitive, and that they had stronger effects. From these results, it was predicted that the study's results would mean that the more biodiverse group of invasives would either have significantly more growth or populations. These results would also be helpful in managing invasive plant species, as well as how they multiple invasives may interact in different plant communities.

Introduction

Around the world, biodiversity has been declining (Chaplin et al, 2000; Pimm, 2000). It is an important ecosystem service, increasing the stability of various ecosystems and providing important resources (Li et al., 2012; Chaplin et al., 2000). Communities become less stable as more species are displaced or go extinct, as there are less niches being filled, less stable food webs and trophic levels, and, if the species is a keystone species, the environment may have large abiotic changes which are unsuited to its current species (Chaplin et al., 2000). One of the major contributors to the decline of biodiversity are invasive species (Pejchar, 2010; Clavero et al., 2005; U.S. Forest Service). Invasive species can be intentionally or unintentionally introduced. They have disproportionate effects on where they invade, and can cause significant negative changes to the environments they inhabit. As more invasives begin to spread however, there are chances that they may begin to overlap each other. It is unknown what general effects this may have on ecosystems or biodiversity as a whole (Grice, 2006), but it would be important for ecosystem management and invasive species removal if these effects are significant enough to warrant action. If two or more species of invasives were grown together, how would they interact with each other? Would they facilitate each other, curb the other, or simply coexist. By using data from a study by Adler et al (2018), these interactions may be estimated and used to guess general interactions, as well as used to predict the possible results of a proposed greenhouse study using two invasive plants, dandelion and mustard, in heterogeneous and homogeneous pairs. If invasive-invasive interactions are more facilitative, then heterogeneous pairings would have larger living populations and more overall growth.

Literature Review

Biodiversity

Biodiversity broadly describes the amount of different taxa in an ecosystem. This can encompass every species in that ecosystem, every ‘large’ taxa, like families and orders, or all species within a taxa. Species diversity can be separated into two measures: species richness, the different kinds of species and species evenness, and the relative number of individuals per species. Different environments have different degrees of diversity, with tundras and deserts having very low diversity, and coral reefs and tropical forests having higher (Gaston, 2000). As biodiversity is dropping from anthropogenic activities (Chapin et al., 2000), it has become more important to preserve it.

There are many pros to preserving biodiversity. For example, higher species richness and evenness can increase the function and stability of an ecosystem. According to Gamfeldt (2008), though monotypes perform better at one or two functions than diverse ecosystems, the more diverse had better overall function. This can be seen in a study where algae was used to remove Cd; though the efficiencies of both monocultures and polycultures were not significantly different, the polyculture was able to remove more due to the presence of both Cd-tolerant and high biomass Cd-sensitive species (Li, et al., 2012). This also shows how biodiversity increases tolerance to stresses and disturbances, like pollution or species invasions. Different species react differently to disturbances, which was believed to be one of the main mechanisms behind the resistance shown by a study on microbial biodiversity (Ashwati et al., 2014). Preserving biodiversity may also help with ecosystem restoration; a study on river restoration found that macroinvertebrates populations could only reestablish if they were source populations already present in surrounding areas, and sites that lacked these populations in their surroundings would have limited improvement (Sundermann et al., 2011). "Biodiversity and its links to ecosystem properties have cultural, intellectual, aesthetic, and spiritual values that are important to society (Chapin et al., 2000)". An example is the value of genetic information from a grass called teosinte, so more viral-resistant corn strains could be produced, and which would have been loss if the area was developed (Chaplin et al. 2000). Another example is phytoremediation, using plants to restore environmental quality. While most of the research done has been mostly observing efficient monotypes, Li (2012) shows that polycultures can remove more than monotypes.

Major threats to global biodiversity are mostly anthropogenic. Currently, habitat destruction is the greatest threat (Pejchar, 2010; Pimm, 2000). According to Pimm, "Generally, many of the species found across large areas of a given habitat are represented in smaller areas of it. So habitat loss initially causes few extinctions, then many only as the last remnants of habitat are destroyed." Invasive species are the second greatest threat to biodiversity (Pejchar, 2010). The second greatest threat, and the next topic of discussion, is invasive species.

Invasive Species

The United States defines an invasive species as a non-native/alien species whose introduction can or may likely cause economic, environmental, or human harm (US Forest Service). These organisms are usually brought to a new ecosystem, accidentally or purposely. The honey bee was brought purposefully, and is used for honey and pollination in commercial agriculture, but also displace native pollinators in an ecosystem (Pejchar et al, 2010). Initial or projected ranges of invasives can also increase due to outside factors. The emerald ash borer, for example, is a beetle that has killed millions of ash trees in the United States and Canada (Matsoukis). With fewer cold days due to climate change, the range of the beetle is believed to extend further north into Canada (University of Waterloo, 2018).

An invasive species can also destabilize the trophic levels of an ecosystem. The cane toad, an invasive species in Australia, causes both ecological and human harm. They breed quickly, it will eat everything smaller than it, and the toxins it secretes not only prevents it from being predated on, but also makes it a danger to humans and pets (National Geographic, 2008). The main problem of the cane toad is that it disrupts the trophic levels of the ecosystem; it depopulates the lower trophic level, which lowers the population of the above levels, and it cannot be predated on by upper trophic levels, meaning there is no natural control for their populations, and the trophic levels become more destabilized as the number of toads grow. Another invasive species, Eurasian milfoil, is an aquatic macrophyte that creates dense mats on the surface of the water, both crowding out and preventing light to native species, and is hardy enough to survive winters and hot, shallow waters (Wisconsin DNR). Instead of directly affecting trophic levels like the cane toad, Eurasian milfoil instead changes the abiotic conditions (light level and available space) of habitats it inhabits, which lowers the environmental quality for native organisms. The trophic levels of these habitats are instead affected at their lowest level, with phytoplankton and submerged macrophytes unable to receive the light they need and their populations are reduced, which also reduces the populations of upper trophic levels in a cascading effect.

As stated earlier, invasive species are the second greatest threat to biodiversity; it is the leading cause of extinction for birds (Clavero et al., 2005), and for plants, “contributed to the decline of 42% of U.S. endangered or threatened species,” and is the main cause of decline for 18% of endangered or threatened species (U.S. Forest Service). The Australian rangelands, which make up 75% of Australia’s plant ecosystems, “are at risk of invasion by one or more species though the severity of current problems varies generally across the rangelands” (Grice, 1996). The economic impact of plant invasions in total are estimated to cost Australia 2.1 billion USD each year (Chapin et, al., 2000). Chaplin also (2000) notes of various invasions that have had large economic consequences; "…the introduction of deep rooted species in arid regions…", "…the presence of rapidly transpiring exotic pines…" in South Africa, and Tamarix invasions in the United States all have reduced usable water, and increased water costs. However, as invasive species continue to spread, it is unknown how they might interact with each other as their ranges overlap (Grice, 1996).

Plant Ecology

Brassica juncea, or Indian mustard, is a perennial herb of the family Brassicacae, or the mustard family (ITIS, n.d.). It can grow more than 1 meter tall, and has long branches. The leaves are obviated and toothed, 30-66 mm long and 2-3.5 mm wide. It is a sessile plant with a root length of 90-120 cm (Purdue University). It has yellow flowers that are 12-15 mm wide and the seed is about 2 mm wide, "conspicuously and evenly reticulated (MacGregor, 1991)." It is a hardy plant that grows in temperate and subtropical climates, thrives in places with hot days and cool nights, with a tolerance range of 6-27 degrees Celsius. Indian mustard can tolerate acidic soils as low as 4.3, as well as a pH as high as 8.3. It is drought resistant, can tolerate precipitation between 500 to 4200 mm, and is less susceptible to insects and pests than other Indian brassicales (Purdue University). The origin of Indian mustard is believed to be central Asia, more specifically Northwestern India, though it is widely distributed in the temperate United States and Eurasia (MacGregor, 1991). It is a widespread crop cultivated for seeds, oil, and greens (Purdue University), as well as biofuels and biomass. This plant is sometimes grown in urban gardens, both for the leaves and seeds. It is a nonnative plant in North America, and is considered a noxious weed in some states (USDA, n.d.). Indian mustard has also been found to be an effective phytoremediator, as they can take up a moderate amount of heavy metals, and have a large biomass. They are ideal for Cd remediation, as they take up Cd more than Pb, though Pb inhibits Cd uptake (R. Johna et al, 2012).

Taraxacum officinale, or the common dandelion, is a perennial herb in the family Asteraceae, which it shares with sunflowers and tournesols (ITIS, n.d.). Though the dandelion has a native subspecies found in western North America, the invasive subspecies is much more proliferate in all of North America (USDA) and practically everywhere in the world (CABI). The plant's origin is believed to be Greece, and it spread through temperate Eurasia (CABI). It is near stemless; said stem is about 1-2.5 cm in length, though it can grow stem-like, leafless, hollow structures called peduncles that are between 5 - 50 cm (CABI), that when broken produce milky sap, or latex (Mitich, 1989). The flower is a bright butterscotch yellow color. It's seed dispersal is called 'aggressive', creating a large amount of seeds that are transported by wind (CABI). It can tolerate soils with a pH from 4.2 - 8.2, and can grow in both full and partial sunlight, though younger plants are not very drought resistant (CABI). This hardiness lets them survive and thrive in urban areas, serving as an important food source for pollinators. These traits also let them serve as bio-indicators, especially of heavy metals (B. Keane et al, 2001). Though the dandelion has benefits, including being completely edible (Mitich, 1989), and its use as a medical herb (CABI; Odigie, 2019), it is classified as and considered a weed in the United States (USDA), probably due to its hardy nature and ability to spread.

Data

The data that is being analyzed comes from a recent paper, "Competition and coexistence in plant communities: intraspecific competition is stronger than interspecific competition" written by Adler et al. (2018). The study intended to analyze multiple papers and data that listed both interspecific and intraspecific plant interactions, in order to see whether interspecific or intraspecific had the greatest effect. They did this by simulating Lotka-Volterra coefficients, calculated the square root of the interspecific interactions of species 1 and 2 vs intraspecific of species 1 and 2, while also comparing the coefficients. They found that intraspecific competition was 4-5 times stronger than interspecific competition, and that most of the effects (67%) of both were negative. 30% had a negative intraspecific effect but positive interspecific effects. The remaining cases were when intraspecific interactions were facilitative and interspecific were not (but this was mostly from greenhouse studies), and when both were facilitative. Using this data, I will see whether or not invasive-invasive interactions are majorly competitive or noncompetitive, and compare them to native-native and native-invasive interactions. Additionally, it would help to predict results for a proposed greenhouse study for invasive-invasive (dandelion & mustard plants) interactions when heterogeneous (dandelion-mustard) or homogeneous (dandelion-dandelion or mustard-mustard). Considering my hypothesis is that heterogenous pairings would have significantly higher growth and populations than homogenous pairings, then invasive-invasive (and by proxy, native-native) pairings would probably have less competitive interactions than native-invasive pairings.

Methods

The data set was provided with the study by Adler et al (2008), was processed to remove white space (empty rows), and then copied into a second sheet. Since interactions in the paper were between a focal species and competitive species, both of which could either be Native, Invasive, or both, population counts for all possible interactions were created. Of the usable interactions, summary statistics (low, quartiles, high, median and mean, range, standard deviation) were created for their competitive coefficients to see how much their interactions affect each other. Lastly, to see whether or not the majority of these specific interactions were competitive or other (coexisting or facilitative), counts were taken for if the coefficients were negative or positive, and if negative coefficients meant competition.

Results

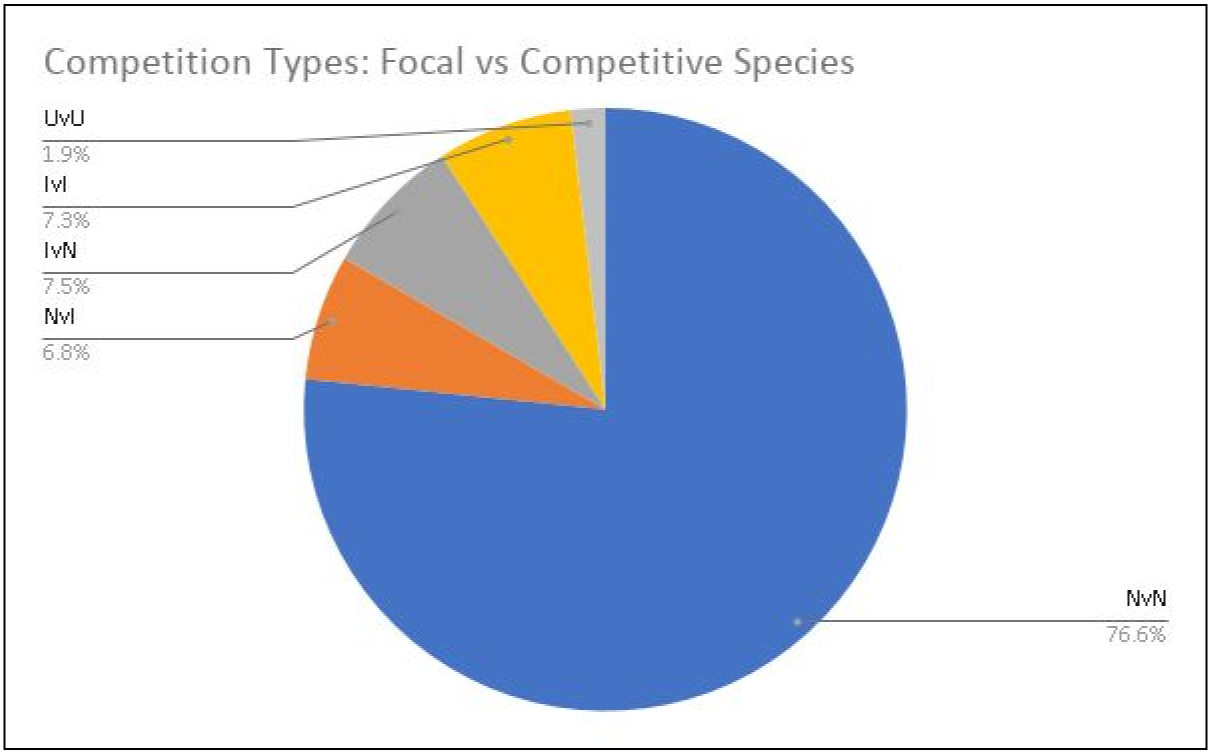

Fig 1: A pie chart showing the distributions of focal origin vs competitive origin types in the study. which are keyed respectively. Native vs Native (NvN) makes up more than three-fourths of all competition.The next prevalent was Invasive vs Native (IvN), Invasive vs Invasive (IvI), Native vs Invasive (NvI) and Unknown vs Unknown (UvU). 4 other types, Unknown vs Invasive (UvI), Invasive vs Unknown (IvU), Unknown vs Naive (UvN), Native vs Unknown (NvU) had 0 counts and were excluded from the figure.

The majority of the 1154 interactions were Native vs Native (NvN), which made up 907 cases. Invasive vs Native (IvN) had 89 cases, Invasive vs Invasive (IvI) had 86 cases, and Native vs Invasive (NvI) had 80 cases. The rest of these cases were unusable unknown cases, which all consisted of Unknown vs Unknown (UvU). After this point, IvN and NvI were combined, as they are functionally the same for the purposes of the analysis.

Table 1: This table details how many of the competitive origin types were competitive for each competition type. Since negative and positive coefficients were not always considered competitive, They were divided into four categories: negative, yes or no negative does mean competition, and positive, yes or no negative does mean competition. Additionally included are the percent that would be considered competitive, which would be the combined negative(yes) and positive(no).

Which Types are Competitive?					
Type	Negative (no)	Negative (yes)	Positive (no)	Positive (yes)	% Competitive
IvI	47	14	21	4	40.7
Either IvN or NvI	67	19	82	2	59.4
NvN	23	173	606	43	92.2

NvN had the highest proportion of competitive interactions, which consisted of 92.2% of all of its interactions. The combined IvN/NvI had 59.4% of all of its interactions be competitive, and IvI had 40.7% of its interactions be competitive. Lack of competition means that the remaining cases could either be facilitation or coexistence, which wasn't found for the remaining cases.

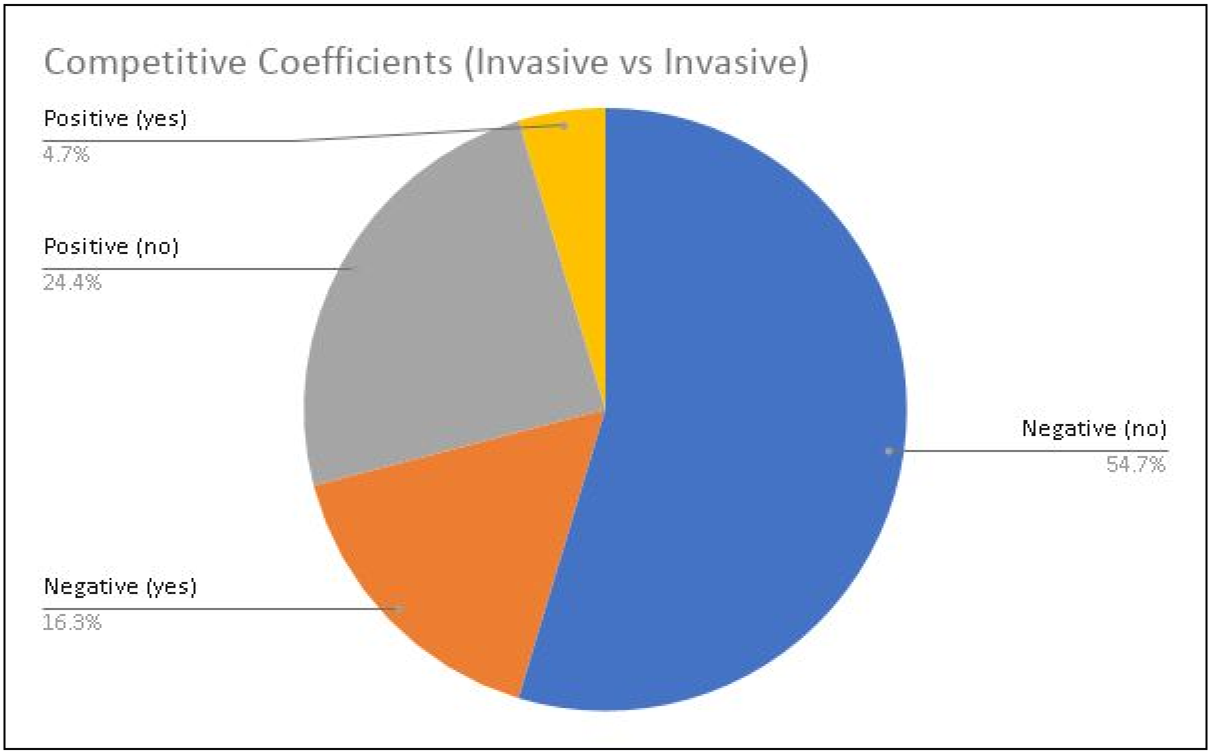

Figure 2: This pie chart is a visual of table 1's data, specifically of the row Invasive vs Invasive. It shows the percent distribution of whether a coefficient was positive or negative, and whether negative coefficients were competitive.

For IvI specifically, a little more than one half of competition coefficients were negative when negativity did not represent competition. The least occuring case were positive coefficients where negativity did indicate competition.

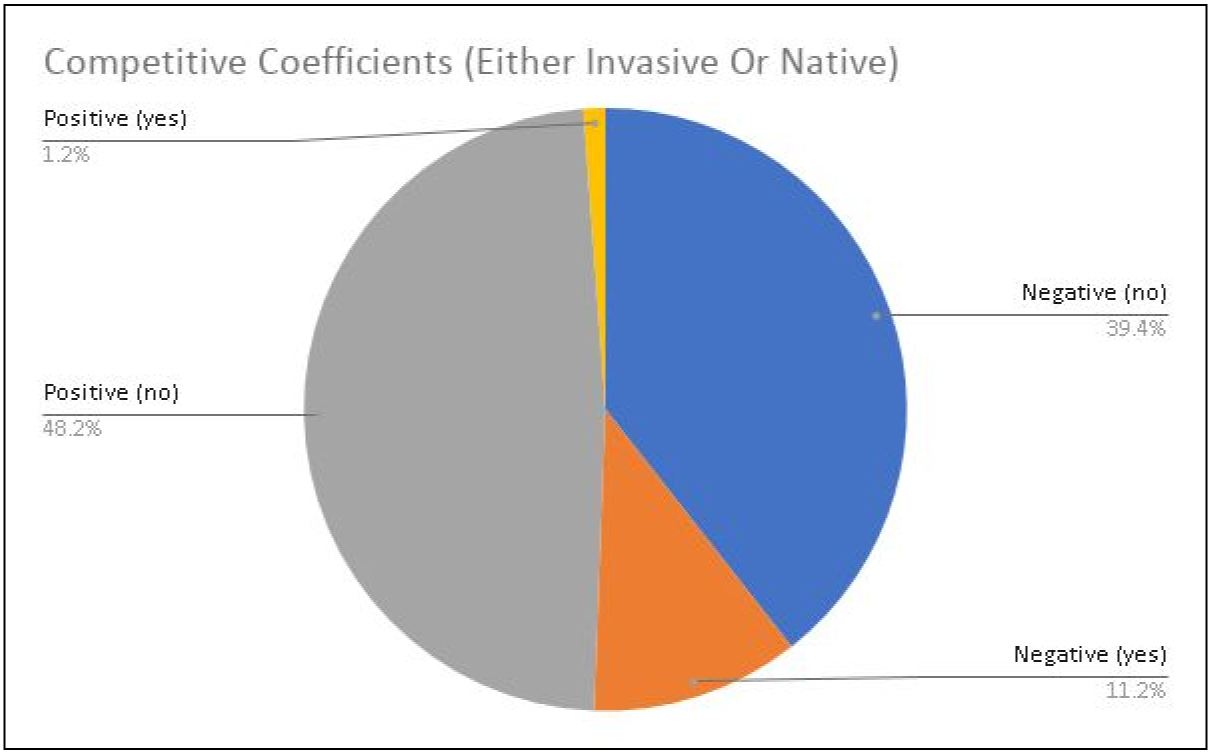

Figure 3: This is a pie chart of the data of Table 1, specifically of the row Either Invasive vs Native or Native vs Invasive. It shows the percent distribution for each case.

Of the combined IvN/NvI cases, the most occuring coefficients were positive when negativity did not indicate competition, and the least occuring were positive cases when negativity did indicate competition.

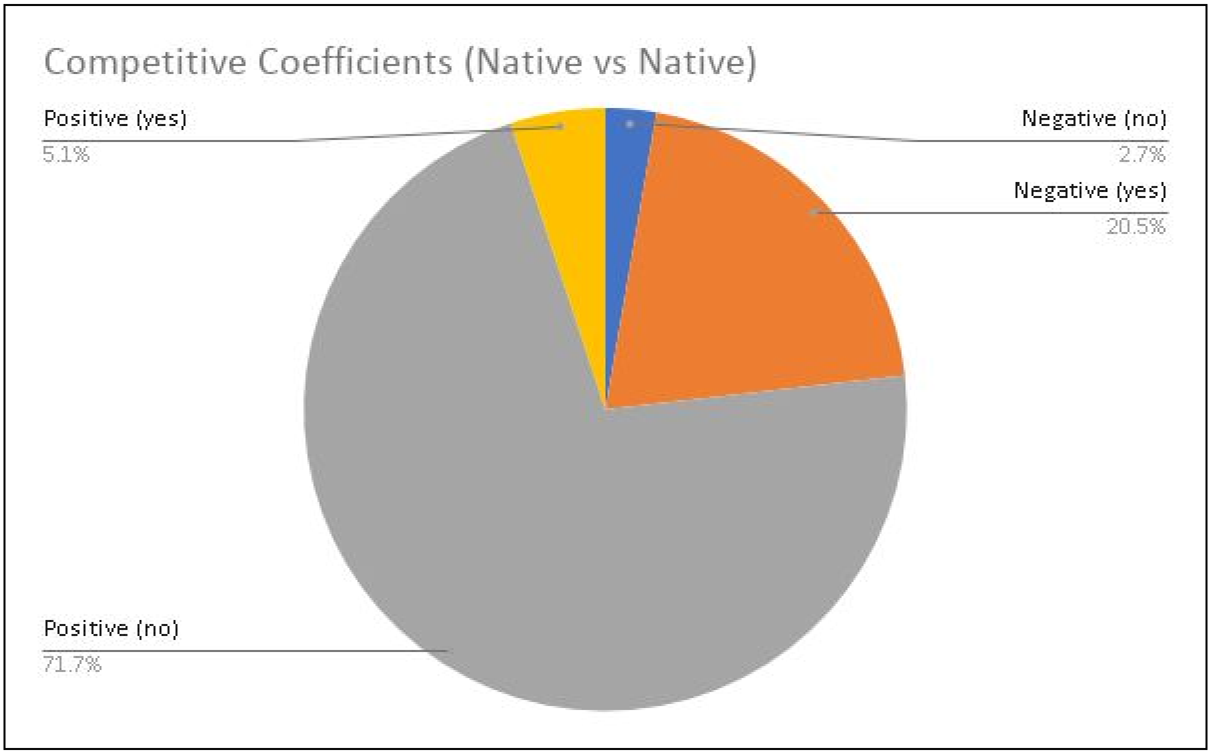

Figure 4: This pie chart is a visual of the data in Table 1, specifically the row Native vs Native. It shows the percent distribution for each case.

The majority of NvN cases were positive when negativity did not indicate competition. The least occuring coefficients were negative when negativity did not indicate competition. For all interactions, positive coefficients with negativity indicated competition were consistently the least occuring, which were always less than 6%.

Table 2: Summary statistics of the coefficients for each focal and competitive interaction, with included average. As seen here, the native vs native has the overall highest high and the lowest lows, though they may be outliers.

Coefficient Summary Statistics of Focal vs Competition Origins								
	Low	Q1	Median	Mean	Q3	High	Range	St. Dev.
IvI	-6.2600	-0.5222	-0.0733	-0.3612	0.0128	1.5600	7.8200	1.0832
IvN or NvI	-16.7008	-0.4454	-0.0009	-0.5381	0.2432	8.4674	25.1682	2.6121
NvN	-451.9000	-0.0056	0.1300	-1.7176	1.0000	244.7000	696.6000	23.6578

NvN had the largest high (244.7000) and the smallest low (-451.9000) of competition coefficients, the largest standard deviation, as well as the least precise range of coefficients (~30 standard deviations across, greatest outlier (low) is around 19 deviations away from quartile). IvI in contrast, had the lowest high (1.5600) and highest low (-6.2600), but also the most relatively precise range (~7 standard deviations across, greatest outlier (low) is around 1.5 deviations away from quartile). The median for all interaction types were greater than their mean, which meant that the data skewed left.

Discussion

With around 40% of IvI interactions being competitive, that would mean the majority of the interactions were either competitive or facilitation. Considering in Adler's study (2018) that facilitation was rare, that would mean most of these interactions are probably competitive. Additionally, since competition coefficients that are farther away from zero means a decrease in interaction, that would mean that IvI had more stronger interactions (or at least, more interactions clustered closer to 0) compared to the other types.

Though the study did have enough interactions of the usable types to analyze, more data would have helped to supplement the less numerous cases (IvN/NvI and IvI), and possibly add or remove skew from the data. Additionally, some of the data points were also greenhouse studies, which the original paper notes that may have been overly skewed. Dividing the data into greenhouse and non-greenhouse may have helped with both removing outliers and for predicting results in the proposed study, but some of the interactions already had a small number, and they would have possibly become even smaller, and more skewed.

From the data, considering that IvI had less competition and stronger overall effects from these interactions, especially compared to native competition and large range of responses, that while invasives do have general stronger effects, they do not compete as much as natives. In the context of the proposed study, this means that the most likely interactions will be either coexistence or facilitation, and the effects they would have will be stronger than compared to native interactions. In a more broader context, we can see how invasives are able to overtake native plant communities. Since many communities, especially those with low stressors and disturbances in their environment, are usually in the last stages of succession, which promotes competitive plants over stress-resistant or disturbance resistant plants, which can be seen in both

Fig. 4 and Table 1. However, competition, inter or intra-specific, usually has a negative effect on the affected plants. Since the majority of invasive interactions are non-competitive, even if they only have coexisting interactions with other species, that is still one less pressure on the fitness of invasive species. However, we see that IvN/NvI interactions are not as overwhelmingly competitive as NvN interactions. While that could mean that there is less competition pressure, there is still a fairly tighter range of responses compared to NvN interactions, which would mean that intra-inter specific effects are not as strong overall as invasive only, but are stronger than nativer only overall. This would reflect how established invasives change plant communities, and in this case, increase the strength of the effects of interactions.

Proposed Study

Proposed Methods

The study would be set up in a temperature controlled greenhouse. Plants would be grown in 2 trays that contained 6 well seed starters with 6 cells each. Each cell would contain 2 seeds, forming a pair. There would be three groups of pairs: heterogenous (one mustard and one dandelion), homogenous mustard (two mustard) and homogenous dandelion (two dandelion). The heterogeneous group would contain 36 pairs, while both homogenous groups would contain 18 pairs. Each pair would be planted into a well, watered, and given a dome to further control conditions.

The plants would be observed for 30 days, with data being collected every 5th day. Data collection would be divided into population and individual growth. Population data would be divided by the major three groups, and consist of the amount of plants that had sprouted, the amount living, and the amount flowered. Individual growth data would be collected for all individual plants, which would later be averaged by group for the day. Each individual would have the following measured: tallest shoot height and number of shoots, largest leaf length and number of leaves. After the 30 day observation period is over, final measurements would be taken, which would consist of all subsequent measurements, root length measurements, final root-shoot ratio and biomass measures for all individuals. This would be done to calculate the growth rate for each individual, as well as the average growth rate for each group. All data would be journaled and placed in a spreadsheet.

Summary data would be divided by both species and group, creating four groups: heterogeneous mustard and dandelion, and homogeneous mustard and dandelion. Individual data would be compiled into mean average shoot length and number, mean leaf length and number, mean growth rate, and mean root-shoot ratio, to plot into graphical comparisons. Additionally, the individual data will be compiled into box and whisker plots to see the general range, skew and variance for each of the four groups. Mean growth rates over time, mean shoot length over time, and populations would be graphed over time. In order to see if the data is significant, they would be verified with regression and T-tests.

Anticipated Results and Discussion

For my hypothesis to be mostly supported, plants in the heterogeneous would have to have significantly more growth and living populations than plants in the homogenous group. At minimum, that would mean taller shoot length, more biomass, and larger average growth rate. While it could mean a higher leaf and root length, the plants may be stymied by both container space and space with other plants. Significantly higher population would mean higher ratios of sprouted to planted, living to sprouted, and flowered (if any) to living.

Table 3: A sample table of data of if the hypothesis is supported and heterogeneous pairs have both higher populations and growth. Non-population data was mostly randomly generated.

Scenario 1: Supported						
Pairs	**Species**	**# Sprouted**	**# Living**	**# Flowered**	**Mean Shoot Length (cm)**	**Average Growth Rate (cm/day)**
Homogenous	Dandelion	18	16	2	31.55	2.8367
	Mustard	18	10	0	49.212	5.9345
Heterogeneous	Dandelion	18	17	5	39.0744	5.3107
	Mustard	18	16	0	52.6764	7.5776

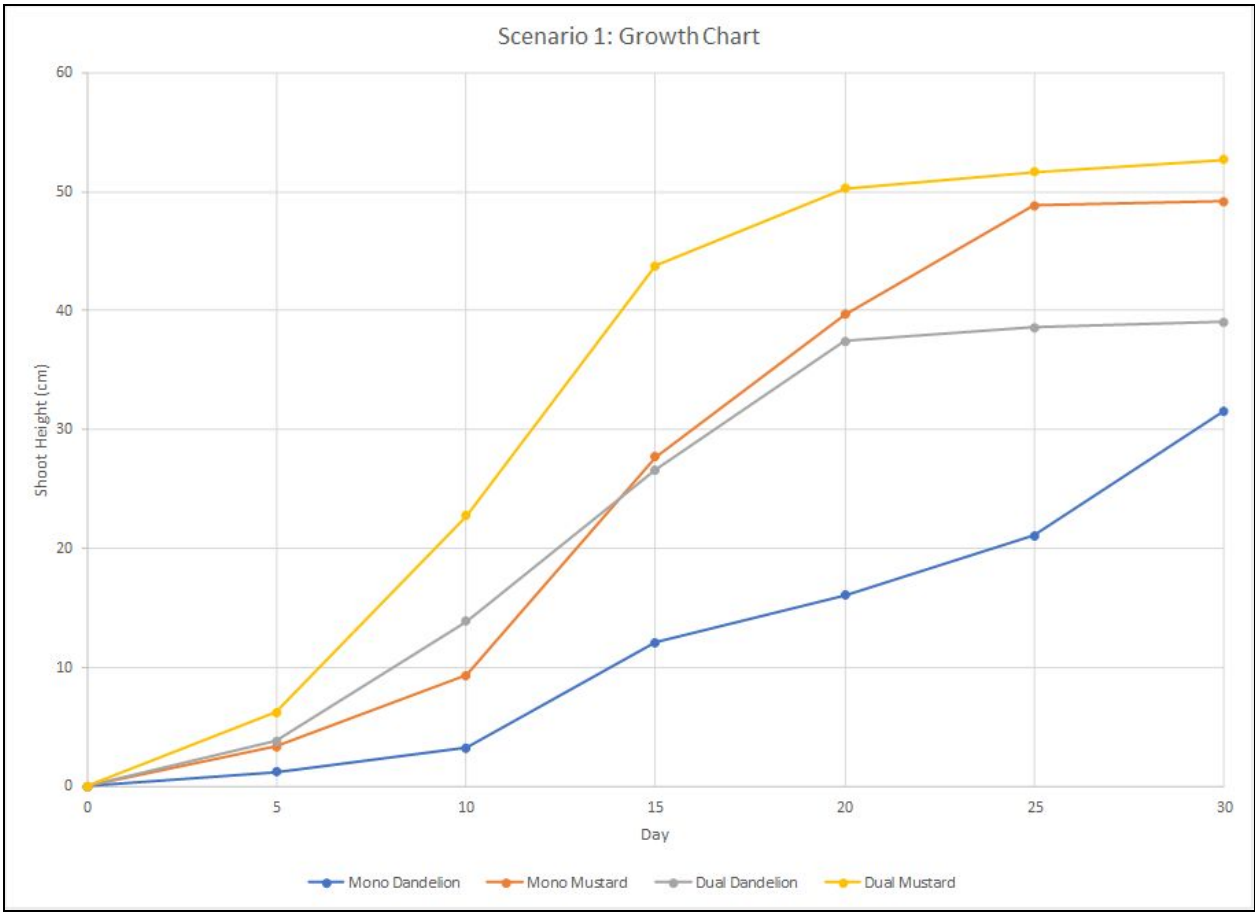

Figure 5: This is a sample figure showing growth over time. Both dual (heterogeneous) dandelion and mustard have higher growth rates than mono (homogenous) dandelion or mustard. All of the data for this chart was randomly generated.

If my hypothesis is only partially supported, then that would mean that either the populations or growth of heterogeneous pairs are either not significantly more than or is significantly less than that of homogeneous pairs. This could mean that the heterogeneous group either has a significantly higher population (but not growth), or that they have higher growth (but not populations). Another possible scenario, though not shown in any figure, is if one species showed significantly higher growth and/or populations in one pair type over ther other.

Table 4: This is a sample data table of if my hypothesis was partially supported. Scenario 2A refers to if heterogeneous pairs had higher populations, but lower growth rates, than homogeneous pairs.

Scenario 2A: Partial Support: Higher Populations, Lower Growth						
Pairs	**Species**	**# Sprouted**	**# Living**	**# Flowered**	**Mean Shoot Length (cm)**	**Average Growth Rate (cm/day)**

Homogenous	Dandelion	18	16	2	39.0744	5.3107
	Mustard	18	10	0	50.7821	5.9241
Heterogeneous	Dandelion	18	17	5	23	2.0667
	Mustard	18	16	0	49.212	5.9345

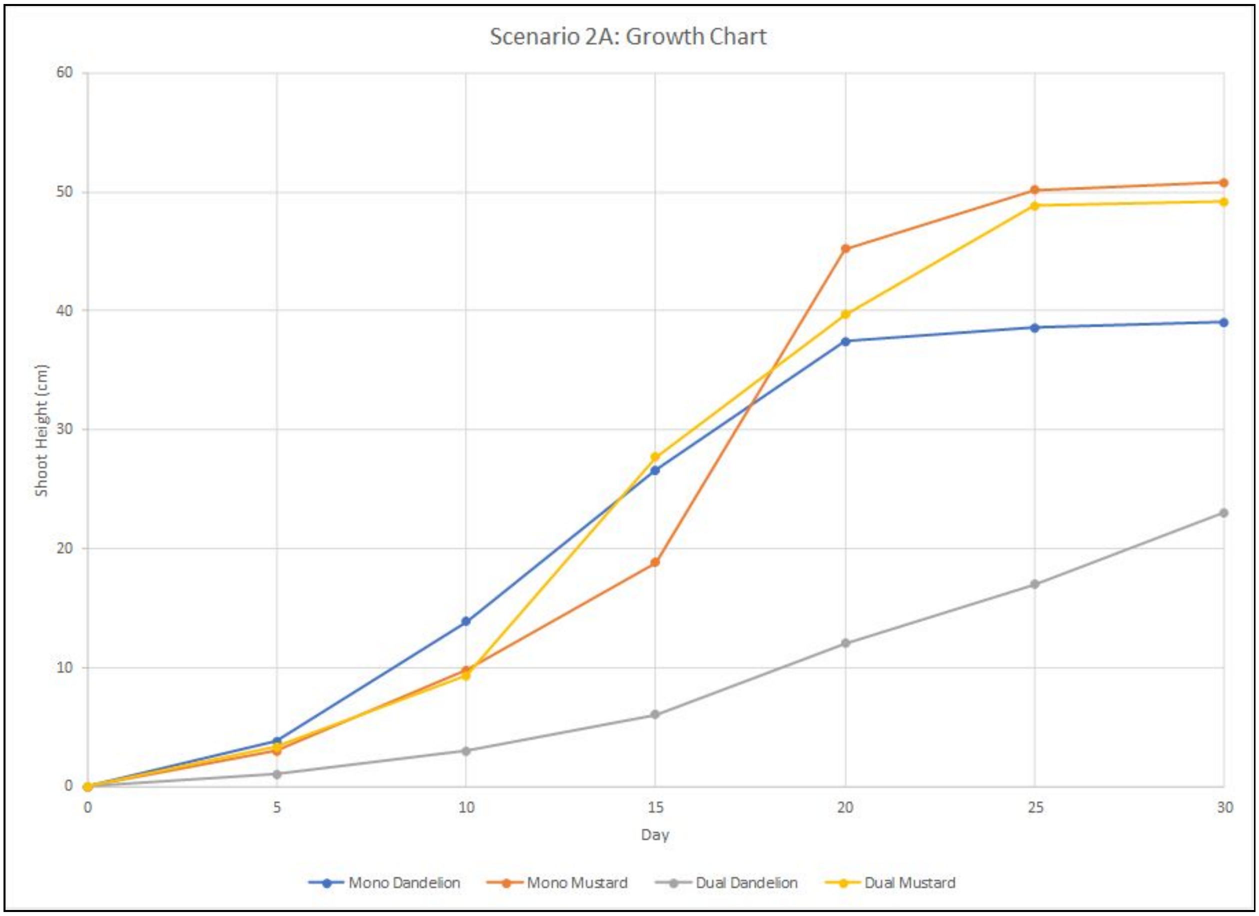

Figure 6: This is a sample graph of if my hypothesis was partially supported. Both homogeneous pairs have higher growth rates than the heterogeneous pairs. The data was mostly randomly generated.

Table 5: This table shows a partially supported hypothesis scenario in a different way: heterogeneous pairs have lower populations, but higher growth rates.

Scenario 2B: Partial Support: Lower Populations, Higher Growth						
Pairs	**Species**	**# Sprouted**	**# Living**	**# Flowered**	**Mean Shoot Length (cm)**	**Average Growth Rate (cm/day)**
Homogenous	Dandelion	18	18	4	31.55	2.8367
	Mustard	18	17	0	48.2598	5.322
Heterogeneous	Dandelion	18	12	0	37.125	3.4292
	Mustard	18	10	0	52.6764	7.5776

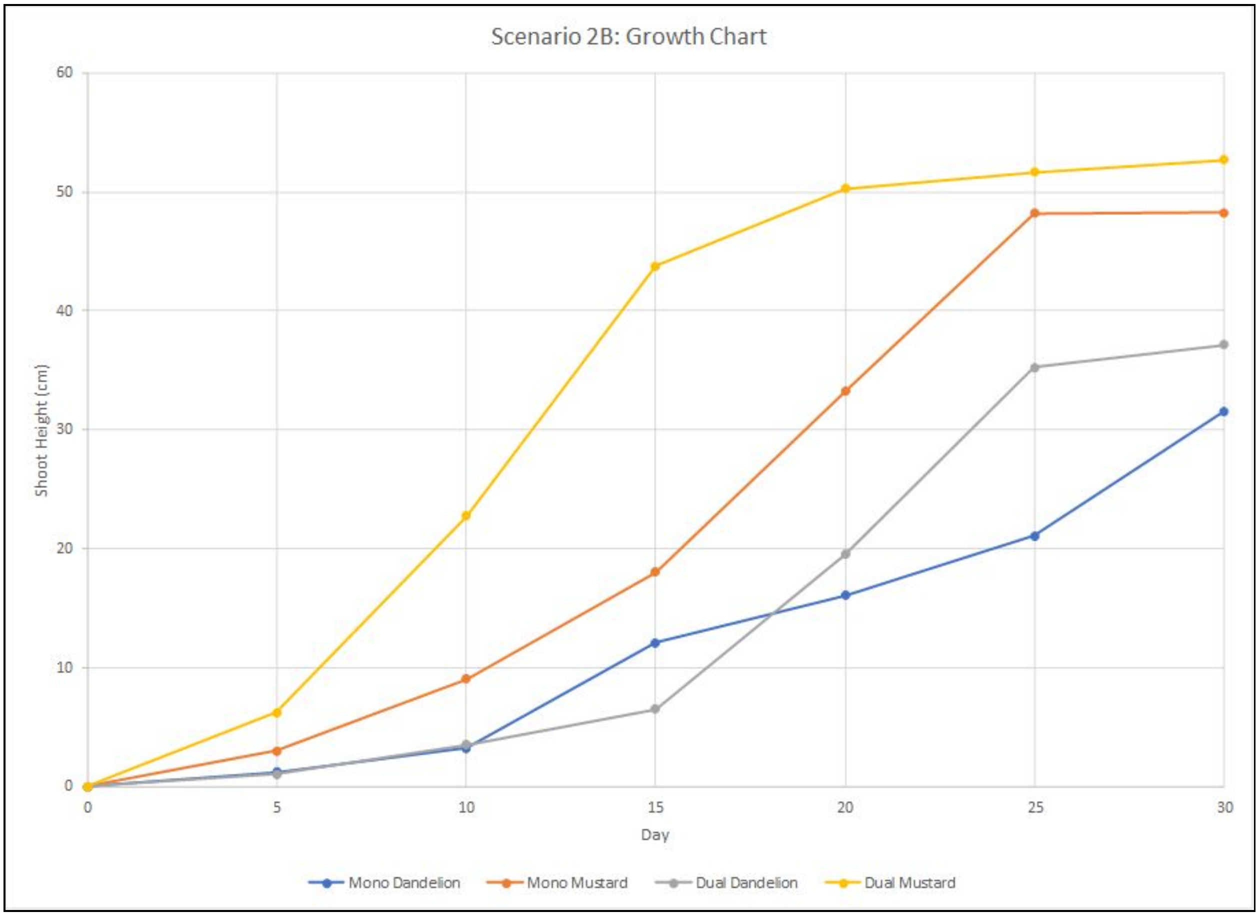

Figure 7: This is a sample graph of if my hypothesis was partially supported. Both heterogenous pairs have higher growth rates than the heterogeneous pair. The data was mostly randomly generated.

The final scenario is if my hypothesis is mostly disproved, and heterogeneous pairs have no significant growth and populations or significantly less growth and populations than homogenous pairs. This also includes a null scenario where there is no significant difference between either group.

Table 6: This is a sample table of if my hypothesis was mostly disproven, and homogenous pairs would have higher populations and growth rate than heterogenous pairs.

Scenario 3: Disproved						
Pairs	**Species**	**# Sprouted**	**# Living**	**# Flowered**	**Mean Shoot Length (cm)**	**Average Growth Rate (cm/day)**
Homogenous	Dandelion	18	18	4	39.0744	5.3107
	Mustard	18	17	0	52.6764	7.5776
Heterogeneous	Dandelion	18	12	0	23	2.0667
	Mustard	18	10	0	48.2598	5.322

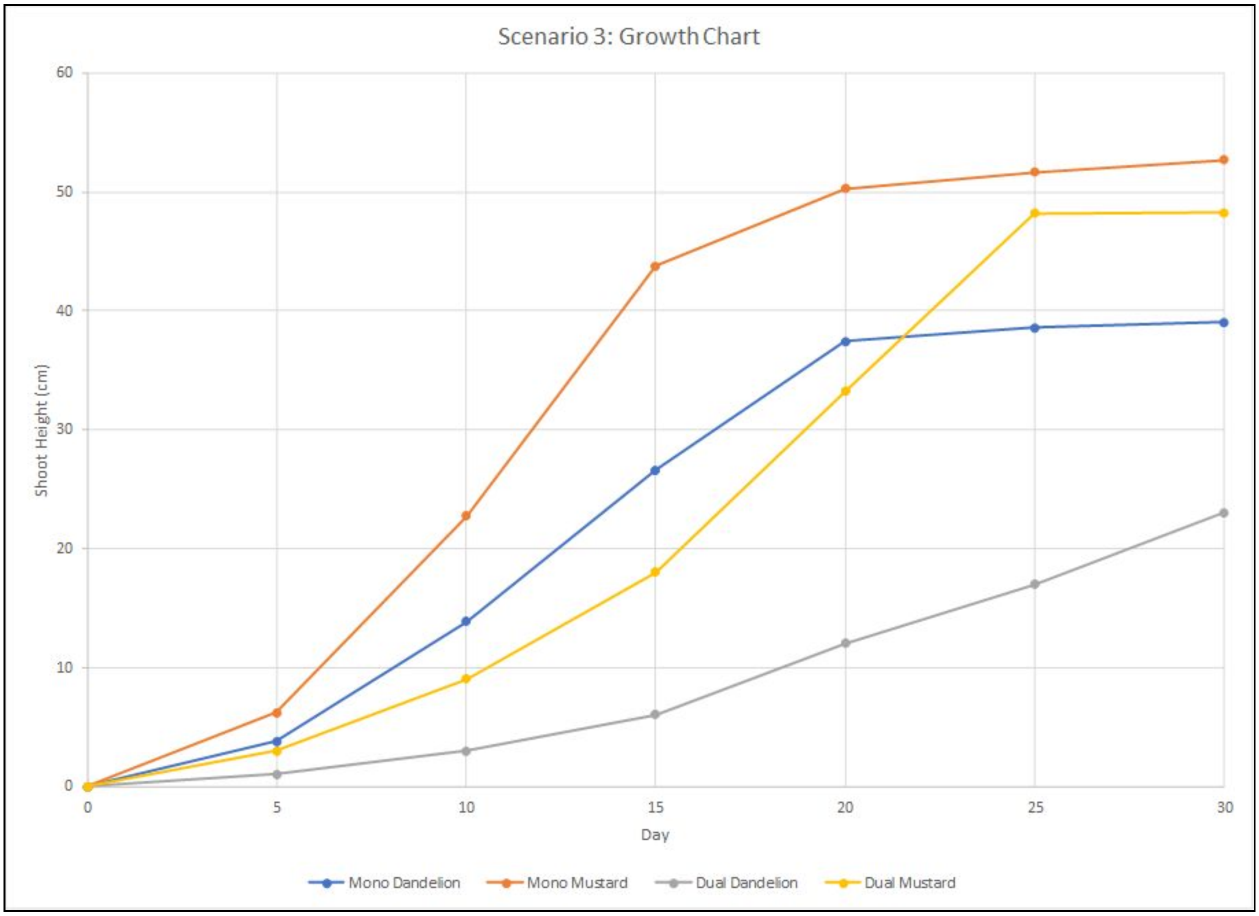

Figure 8: This is a sample graph of growth over time if my hypothesis was disproved. Homogenous mustard and dandelion have a higher growth rate than heterogeneous mustard and dandelion. This data was mostly randomly generated.

From the results of analyzing the Adler paper, the most probable scenario of all of these is scenario 2. If these interactions are similar to the data, then while a good proportion of the interactions aren't competitive, they would still limit each other to some degree. If these interactions are more facilitative, then heterogeneous pairs would have higher growth (Scenario 2B), but since facilitative interactions were rare, then they would probably have higher populations (Scenario 2A).

As stated previously, the anticipated results could have been improved by taking into account greenhouse interactions vs non-greenhouse interactions, but there were not enough data points in invasive-invasive interactions to justify a further split. However, there are still some sources of error and complications that can be pointed out. The space allotted for each pair is rather small, which could stress the plants and cause interactions that would not happen in the field. Additionally, certain conditions and interactions do not fully model the environment. Here, there is only one individual acting on another individual, and vice-versa. In even a small plant community, there are multiple individuals interacting with other individuals and vice-versa. The conclusions drawn from the current methods may not fully reflect how the intraspecific interactions of communities and interspecific and intraspecific interactions between populations.

The major two improvements to the current methods could be to either add population gradients, or to add a native species. Population gradients would have different proportional populations of two different species, in order to see whether the interactions between the two species changes when population is also taken into effect. Adding a native plant can show how invasive-invasive interactions may affect a native community. This can be done by growing native plants alongside invasive ones, or growing invasive plants with an 'established' native plant. Studying these interactions would not only add more depth to these interactions, but also would be good for invasive management.

Concluding

Using Adler helped to model how invasive and native interactions may play out in nature. While it may not fully encompass all interactions, especially in more biodiverse areas, it is a good starting point for how invasives out-compete other plants, and what may happen in communities taken over by invasives. If more invasive plants mean less competition and stronger interaction effects, it would explain why these plants are easily able to invade into these communities. Though diverse communities have better resistance against invasives, we can see that this may hold stronger for invasives, which would be important for managing them, especially if they overlap with each other in multiple communities.

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