SEATTLE PARKS AND RECREATION / GREEN SEATTLE PARTNERSHIP

SEEDLING SURVIVAL REPORT

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Executive Summary

Seattle Parks and Recreation (SPR), working with the Green Seattle Partnership, plants thousands of trees each year for restoration projects, and seeks more information about the success of these plantings. This Seedling Survival Report (Report) surveyed and measured seedlings in areas that were planted in the 2017-2018 winter planting season. Surveys included:

- 86 100-foot linear transects
- 25 1/10th-acre permanent plots.
- Surveys took place in a range of conditions, including under-planting existing canopies to plantings in newly-created canopy gaps.

Seedling Density: Surveyed seedling densities were lower than the contracted planting densities, due to a combination of seedling mortality where blue-and-white ribbon (indicating planting in the 2017-2018 season) blew away or was covered, ribbons were omitted or fell off, or the stratified survey design missed areas of dense plantings where planting was variable.

Over-planting can lead to competition-induced mortality starting in 10 to 15 years. Four sites have high seedling densities greater than 350 seedlings per acre.

Mortality: Douglas-fir, western redcedar, and western white pine suffered the highest mortality rates (20%, 24%, and 25%, respectively).

- High shrub cover was a strong predictor of mortality.
- Sites that underwent invasive species removal and site preparation previous to planting have lower mortality rates (average 3.5%) compared to sites where seedlings were planted amid existing ground vegetation (average 17.7%).
- Shade-tolerant species suffered relatively higher mortality in open-canopy settings (21% vs 10%), possibly due to high shrub cover and/or drier soil moisture conditions during summer.

Live Seedling Success: Only two shade-intolerant species (Douglas-fir, Sitka spruce) showed statistical correlations between increased height and more open canopies. Variability in live seedling success in the first year following planting may be due to microsite conditions and seedling stock rather than canopy or shrub cover.

Permanent Plots: Permanent plots showed similar density and mortality results compared to the transect data, typically within about 5% of the transect averages. The most powerful value of permanent plots will be future repeat measurements to assess longer-term seedling survival.

Recommendations for Future Planting Projects

1) Plant shade-tolerant species in sites that are likely to retain summer soil moisture.
2) Avoid planting projects in areas with high shrub cover, even native shrub cover. Alternatively, cut back competing shrubs, even native species, five to 10 feet around seedlings.
3) Prioritize planting projects in areas that have undergone site preparation in the form of invasive plant removal. Mortality rates are lower in these sites.
4) Re-measurement, particularly permanent plots, will help inform long-term seedling survival.

Contents

I. Need for Seedling Surveys

Seattle Parks and Recreation (SPR), working with the Green Seattle Partnership (GSP), plants thousands of trees each year for restoration projects, and seeks more information about the success of these plantings. This Seedling Survival Report (Report) surveyed and measured seedlings that were planted by contractors in the 2017-2018 winter planting season (referred to as the 2018 plantings). Our analysis of the results focuses on seedling mortality and the factors that influence seedling mortality and survival for which we have data. We compare our survey densities to the planting densities that were prescribed in the contract documents shared with the planting contractor crews, often referred to as “contractor plantings,” compared to the “measured” or “surveyed” results from our surveys.

II. Methods

A. Survey Design

Each forested property managed by SPR is broken down into units called zones. The seedling surveys were conducted through a combination of linear transects along with permanent plots. Transects were established on a grid, and plots were placed to capture areas that fell outside of the transect grids and were utilized in smaller acreages where transect grids wouldn't cover the area well. The number of transects and plots depended on the size of the zone shown in Table 1. The transects were established along a stratified random grid, with transects sequenced end-to-end, or perpendicular through the mid or end point. Transects laid out parallel are spaced 100' apart. The survey wide associated with each transect is 12 feet on both sides of the centerline, for a 24-foot by 100-foot sample area (0.055 acres per transect). Plots were established roughly on a grid with a size of 1/10th acre (radius of 37.2 feet from center). These plots were monumented at the center with rebar and referenced with GPS and witness trees twin the expectation that they will be re-measured in the future. Transects may also be repeated but transects were not monumented for exact re-measure; transects rely on a sample approach where transects cover sufficient proportion of the zone to capture variability. All seedlings were recorded that fell within the plot or transect boundaries.

The transect and plot grids were established ahead of time using GIS and navigated to using GPS and georeferenced maps. Each 100' transect was delineated using a tape-measure and every seedling within 12' on either side of the transect was recorded, using a 6-foot piece of PVC pipe to measure off the transect line. See Figure 1 in Section IV-B for a sample transect map. The data collected for each seedling includes species, height, diameter, and vigor (present condition / likelihood to survive). Data on the microsite conditions of each seedling such as canopy closure, shrub cover, and invasive plant species was also collected. Canopy closure, tall shrub, and short shrub cover data was collected by assigned one of six percent cover ranges for each seedling: 0%, 1-10%, 11-25%, 26-50%, 51-75%. 76-100%.

See Seedling Monitoring Survey Protocol for full data collection procedure.

Table 1: Transect and plot grids.

Planting Area Acreage	Transect Distance (Ft)	Transect Count	Permanent Plots
0.1 to 0.25	None	None	1
0.25 to 0.5	None	None	1
0.5 to <1	None	None	1
1 to 4	100	3 / acre	1 / acre
5	100	10 (2 / acre)	None
10	100	20 (2 / acre)	None
20	100	40 (2 / acre)	None

Table 2: Vigor scale definitions

Vigor Score	Seedling Observations
High	Vigorous tree likely to survive. Full crown, no damage, competitive.
Medium	Moderate crown, some discoloration or damage, crowded by vegetation.
Low	Stressed. Discolored/ missing foliage, weak crown, damaged, suppressed.

B. Species List

A total of 19 different seedling species were surveyed.

Table 3: Species surveyed

Species Code	Latin Name	Common Name
ABGR	*Abies grandis*	grand fir
ACMA3	*Acer macrophyllum*	bigleaf maple
ALRU2	*Alnus rubra*	red alder
ARME	*Arbutus menziesii*	Pacific madrone
CONU4	*Cornus nuttalli*	Pacific dogwood
COSE16	*Cornus sericea*	red-osier dogwood
FRLA	*Fraxinus latifolia*	Oregon ash
FRPU7	*Frangula purshiana*	cascara
PICOC	*Pinus contorta var. contorta*	shore pine
PIMO3	*Pinus monticola*	western white pine
PISI	*Picea sitchensis*	Sitka spruce
POTR15	*Populus trichocarpa*	black cottonwood
PREM	*Prunus emarginata*	bitter cherry
PSME	*Pseudotsuga menziesii*	Douglas-fir
SASC	*Salix scouleriana*	Scouler's willow
SALUL	*Salix lucida*	Pacific willow
TABR2	*Taxus brevifolia*	western yew
THPL	*Thuja plicata*	western red cedar
TSHE	*Tsuga heterophylla*	western hemlock

III. Site Descriptions and Survey Results

Site Descriptions and Survey Results Highlights:
Seedling surveys included 86 100-foot transects and 25 1/10th-acre permanent plots. Surveys took place in a range of conditions, including under-planting existing canopies to plantings in newly-created canopy gaps. Surveyed seedling densities were lower than the contracted planting densities, possibly due to a combination of seedling mortality where blue-and-white ribbon (indicating planting in the 2017-2018 season) blew away or was covered, ribbons were omitted or fell off, or the stratified survey design missed areas of dense plantings where planting was variable.

These results (Table 4) pertain to seedlings recorded along the transect surveys conducted in summer 2018. Seedlings marked with blue-and-white striped flagging were planted in winter and spring of 2018. In total, 12 zones were surveyed with 86 transects.

Table 4: Surveyed zones

Park	Zone	Planted Acres	Number of Transects	Number of Permanent Plots	% of zone acreage covered by survey
Arroyos Natural Area	Arroyos 47th Ave SW	2.3	6	2	23%
Carkeek	3A	5.3	7	4	15%
Discovery	Wolf Tree North	4.3	8	4	20%
East Duwamish Green Space	Chicago	1.8	5	2	26%
East Duwamish Green Space	EDGS Rose	2.2	6	1	20%
Schmitz Preserve	Schmitz Blvd Slope	0.6	2	0	17%
Seward Park	MF9	4.4	7	4	18%
West Duwamish Green Space	Maduzia Gap	8.2	16	0	11%
West Duwamish Green Space	PPGS2	4.6	10	5	22%
West Duwamish Green Space	PPGS3	6.3	12	0	11%
West Duwamish Headwaters Green Belt	AW2	1.3	4	2	34%
Yesler Creek Headwaters	South Ravine Southend	1.2	3	1	22%
Totals	**12 zones**	**42.7**	**86**	**25**	**Weighted Average 17.2%**

A. Zone Descriptions

Arroyos 47th Ave SW, Arroyos Natural Area

Arroyos 47th Ave SW is a long and steep 2.3-acre strip of coastal forest. It has almost full canopy closure except for a few open patches. It has a sparse understory cohort of mostly young bigleaf maple, with occasional conifer regeneration (though not within the survey transects). Six transects were completed in this zone. A total of 157 SPA were observed with a mortality rate of 13.5%. The 90% confidence interval is 100-214 SPA. Planting records show planting density of 299. PSME and FRPU7 dominated the observed species mix.

3A, Carkeek Park

3A is a 5.3-acre sites surrounding a steep ravine with a perennial stream. The overstory is patchy, with areas of closed and open canopy. Seven transects were completed in this zone. A total of 358 SPA were observed with a mortality rate of 22.5%. The 90% confidence interval is 189-526 SPA. Planting records show planting density of 297. PSME dominated the observed species mix. A few individual FRPU7 and PISI with blue and white ribbon were observed but those species are not listed in the planting records. Many of the planted seedlings were protected with wire cages, with the hope of increasing survival.

Wolf Tree North, Discovery Park

Wolf Tree North is a 4.3-acre site located near the Daybreak Star Center in Discovery Park. The overstory is very patchy, with areas of high canopy closure interspersed with canopy gaps. In the understory, tall shrubs often shaded out seedlings. Eight transects were completed in this zone. 163 SPA were observed with a mortality rate of 0%: though some dead planted seedlings were visually observed outside of the survey transects. The 90% confidence interval is 108-214 SPA. Planting records show planting density of 141. PISI, FRPU7, and THPL dominated the observed species mix. A few individual ACMA and TSHE with blue and white ribbon were observed, but these species are not listed in the planting records.

EDGS Chicago, East Duwamish Green Space

EDGS Chicago is a 1.8-acre site with flat terrain and a small stream / wetland area in the center. The understory was once dominated by blackberry, which was recently cut and mulched down. The wet areas are populated by native wetland plants. The canopy closure tends to be very thin, with high sun exposure. Five transects were completed in this zone. A total of 134 SPA were observed with a mortality rate of 5.1%. The 90% confidence interval is 113-170 SPA. Planting records show planting density of 176. ABGR, PISI, and THPL dominated the observed species mix.

EDGS Rose, East Duwamish Green Space

EDGS Rose is a 2.2-acre site with varying terrain from flat to steep slope. The understory of this site was once dominated by blackberry, which was cut and cleared. There is very little remaining shrub cover. The canopy closure tends to be very dense. Six transects were completed in this zone. A total of 112 SPA were observed with a mortality rate of 2.7%. The 90% confidence interval is 59-165 SPA. Planting records show planting density of 154. ABGR and THPL dominated the observed species mix.

Schmitz Blvd Slope, Schmitz Preserve Park

Schmitz Blvd Slope is a 0.65-acre narrow strip of park along a bike and pedestrian path that was recently cleared of blackberry and other invasive plants. The site has an open canopy with a couple large maple trees overhanging the site creating pockets of shade. Two transects were completed in this zone. The zone has 1,116 stems per acre (SPA) with 2.4% mortality recorded in the 2018 planting stock. Planting records show a planting density of 617 SPA with a 90% confidence interval of 0-2893 SPA. We observed PSME, FRPU7, and ALRU2 as the dominant species.

MF9, Seward Park

MF9 is a 4.4-acre site with flat terrain. The canopy is closed since much of the zone is populated with large mature conifers. Seven transects were completed in this zone. A total of 54 SPA were observed with a mortality rate of 18.2%. The 90% confidence interval is 27-81 SPA. Planting records show planting density of 107. PSME, and THPL dominated the observed species mix.

Maduzia Gap, West Duwamish Green Space

Maduzia Gap is an 8.3-acre site comprising a wide range of terrain, from flat to steep slopes, and vegetation conditions from sunny openings to full canopy. In general, this zone is characterized by very dense shrub cover similar to PPGS2 and PPGS3. Some bigleaf maple and red alder were cut to create canopy openings. Sixteen transects were completed in this zone. A total of 129 SPA were observed with a mortality rate of 22.8%. The 90% confidence interval is 94-165 SPA. Planting records show planting density of 229. ABGR, THPL, TSHE, and PSME dominated the observed species mix. A few ARME were also found in Maduzia Gap which were not on the planting list.

PPGS2, West Duwamish Green Space

PPGS2 is a 4.7-acre site comprising a wide range of terrain, from flat to steep slopes, and vegetation conditions from sunny openings to full canopy. In general, this zone is characterized by very dense shrub cover. Some bigleaf maple and red alder were cut to create canopy openings. Ten transects were completed in this zone. A total of 171 SPA were observed with a mortality rate of 19.1%. The 90% confidence interval is 117-224 SPA. Planting records show planting density of 227. ABGR, THPL, and TSHE dominated the observed species mix.

PPGS3, West Duwamish Green Space

PPGS3 is a 6.3-acre site comprising a wide range of terrain, from flat to very steep slopes, and vegetation conditions range from sunny openings to full canopy. In general, this zone is characterized by very dense shrub cove similar to PPGS2. Some bigleaf maple and red alder were cut to create canopy openings. Twelve transects were completed in this zone. A total of 138 SPA were observed with a mortality rate of 27.5%. The 90% confidence interval is 104-171 SPA. Planting records show planting density of 232. ABGR, THPL, TSHE, and PSME dominated the observed species mix.

AW2, West Duwamish Headwaters Green Belt

AW2 is a flat and open 1.25-acre site surrounded by houses. This was cleared of invasive plants and has abundant scattered bitter cherry. The site abuts a slope and has intense sun exposure. Four transects were completed in this zone. A total of 567 SPA were observed with a mortality rate of 5.6%. The 90% confidence interval is 382-752 SPA. Planting records show planting density of 604. PSME dominated the observed species mix, with an even mix of ALRU2, ABGR, THPL, and others.

South Ravine Southend, Yesler Creek Headwaters

South Ravine Southend is a 1.2-acre rectangular restoration site located adjacent to a strip of condominiums. It was cleared of invasive species and replanted in winter of 2018. 30-40% of the site is a wetland and did not appear to be planted. Three transects were completed in this zone. A total of 375 SPA were observed with a mortality rate of 1.6%. The 90% confidence interval is 328-422 SPA. ABGR and THPL dominated the observed species mix. We did not obtain contractor planting records for this zone.

Tables with zone summary data are located in Appendix B

Zone Summaries

Table 5: Summary of all the zones surveyed

Park	Zone	Acres	Number of Transects	Number of Plots	Contracted SPA	Surveyed SPA *(90% confidence)*	Live SPA	Dead SPA	Mortality Rate
Arroyos Natural Area	Arroyos 47th Ave SW	2.3	6	2	299	157 *(100 to 214)*	136	21	14%
Carkeek	3A	5.4	7	4	297	358 *(189 to 526)*	277	80	23%
Discovery	Wolf Tree North	4.3	8	4	141	161 *(108 to 214)*	161	0	0%
East Duwamish Green Space	EDGS Chicago	1.8	5	2	176	142 *(113 to 170)*	134	7	5%
East Duwamish Green Space	EDGS Rose	2.2	6	1	154	112 *(59 to 165)*	109	3	3%
Schmitz Preserve	Schmitz Blvd Slope	0.7	2	0	617	1116 *(0 to 2893)*	1089	27	2%
Seward Park	MF9	4.4	7	4	107	54 *(27 to 81)*	47	10	18%
West Duwamish Green Space	Maduzia Gap	8.3	16	0	229	129 *(94 to 165)*	100	29	23%
West Duwamish Green Space	PPGS2	4.7	10	5	227	171 *(117 to 224)*	138	33	19%
West Duwamish Green Space	PPGS3	6.3	12	0	232	138 *(104 to 171)*	100	38	28%
West Duwamish Headwaters Green Belt	AW2	1.3	4	2	604	567 *(382 to 752)*	535	32	6%
Yesler Creek Headwaters	South Ravine Southend	1.2	3	1	No Data	375 *(328 to 422)*	369	6	2%

B. Surveyed vs. Contracted Planting Density

Table 6 below shows the planted and surveyed SPA difference and percent difference for each zone. The percent difference ranges from -47% to 81%. The percent difference column shows the positive or negative percent difference.

Table 6: Planted versus surveyed SPA

Zone	Surveyed Total SPA	Planted SPA	Difference	% Difference
Arroyos 47th Ave SW	157	299	-142	-47%
3A	358	297	61	20%
Wolf Tree North	161	141	20	14%
Chicago	142	176	-34	-20%
EDGS Rose	112	154	-42	-27%
MF9	54	107	-50	-47%
Schmitz Blvd Slope	1116	617	499	81%
Maduzia Gap	129	229	-100	-44%
PPGS2	171	227	-56	-25%
PPGS3	138	232	-94	-41%
AW2	567	604	-37	-6%
South Ravine Southend	375	No data	375	-

In most zones, measured seedling density is lower than the contracted planting density. We took in to account uncertainty within the data by calculating 90% confidence intervals for each zone, which is a statistical measurement that provides a range of possible values above and below the average value, based on whether the data are variable (i.e., the transects had a wide range of values) or if there is a small sample size. When considering the range of possible values, of the 11 zones that had data for contracted planting density, seven zones still showed our measured values were lower than the contracted planting densities. We can think of three reasons why our values are consistently low; some or all of these may have contributed to the under-counting.

1) Seedlings died and the blue-and-white ribbon was covered with leaf litter or blew away

Only seedlings that were explicitly flagged with the blue-and-white-striped flagging were counted as 2018 seedlings. Dead seedlings are difficult to identify.

2) Contractors either did not flag all seedlings with blue-and-white ribbon, or ribbon came off some of the planted seedlings

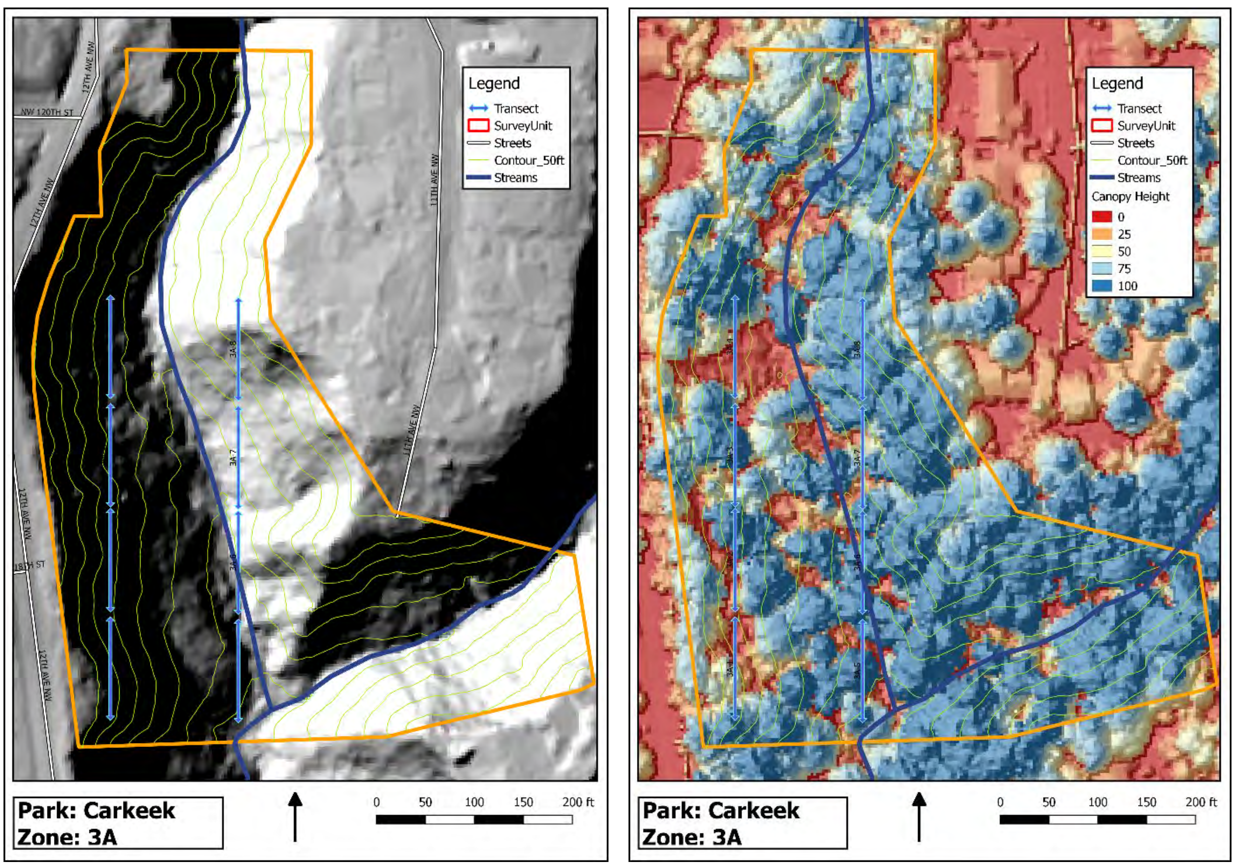
Some untagged seedlings appeared to have been planting in 2018, but since they were not tagged, or their flagging had disappeared, these seedlings were counting only in total seedlings and not 2018 seedlings

3) If plantings were not well-distributed throughout the planting area (i.e., contractors planted more densely in some areas than other), the layout of transects and plots could have missed dense planting pockets

Many of the planting contractors stated that seedlings were clumped in areas more suited to seedlings or left sparse in areas that were not well suited to seedlings. For example: a large sunny canopy opening would be planted with a high density of Douglas-fir, or a wet shady area would be planted more heavily with Sitka spruce. The transects were established on a defined grid system, which by design did not vary based on planting density. This design captured a high proportion of the planting area, and sampled well throughout the zone, but could have missed or under-sampled high-density planting locations.

We show Zone 3A in Carkeek Park as an example of how terrain and canopy influence planting locations (Figure 1). The riparian corridor at the bottom of the ravine resulted in the west side of the ravine planted densely, and much of this density was capture in the transect survey. The riparian corridor and the bowled-out area in the center of the map, up the eastern side of the ravine, is planted sparsely.

Figure 1: Example of variable planting: Carkeek Park, zone 3A. Left: the steep slopes influence planting. Right: Canopy closure (from LiDAR imagery) also influences planting.



The LiDAR imagery shows the canopy structure in zone 3A. Red signifies very short trees, shrubs, or bare ground which indicates a canopy opening, while blue shows a more closed canopy. Based on the canopy analysis from this LiDAR data, the west side has patches of open canopy, which offer planting space even in areas where large overstory trees do exist. The riparian corridor and the east side show a much more closed canopy. The average canopy closure range for the west side is 11-25%, compared to the riparian corridor and east side which is 51-75%. The east side and riparian corridor also have a higher level of short and tall shrubs. Shrub cover is measure in the same percentage ranges as canopy closure.

Table 7: Zone 3A Canopy closure and shrub cover

	West	East	Zone Average
Canopy Closure	11-25%	51-75%	51-75%
Tall Shrubs	1-10%	11-25%	1-10%
Short Shrubs	11-25%	26-50%	26-50%

C. Total Seedling Density

Seedlings in addition to those flagged with striped blue-and-white flagging were observed and recorded when conducting the surveys. These additional seedlings are either naturally regenerated, planted seedlings from prior years, or planted in 2018 but lost their flagging. For this section, we assume seedlings without blue-and-white flagging were natural regeneration or were planted in previous years. Each seedling planting year is denoted by a different color of flagging. The year origin of seedlings planted in prior years is determined by what color of flagging was tied to it. Appendix A: Flagging Color shows flagging color and planting year. Seedlings from four different years were counted within the survey transects. 2018: blue and white stripe, 2014: black and yellow stripe, 2013, pink with black dots, and solid red which is not listed.

All Seedlings

Table 8 compares the 2018 seedling SPA and total seedling SPA. Total SPA includes 2018 seedlings, prior year planted seedlings, and naturally regenerated seedlings. SPA differences range from 0% to 32% with an average of 11%.

Table 8: 2018 SPA to total SPA comparison

Zone	Total SPA	2018 SPA	Difference	Percent Difference
3A	168	161	7	4%
Arroyos 47th Ave SW	250	171	80	32%
AW2	175	157	18	10%
Chicago	124	112	12	10%
EDGS Rose	171	142	29	17%
Maduzia Gap	155	129	26	17%
MF9	54	54	0	0%
PPGS2	360	358	3	1%
PPGS3	192	138	54	28%
Schmitz Blvd Slope	1116	1116	0	0%
South Ravine Southend	375	375	0	0%
Wolf Tree North	617	567	50	8%

Seedling not planted in 2018 were analyzed as a single category instead of breaking down the data into each year. Table 9 compares the tally of previous plantings and natural regeneration for live seedlings only (we recorded only four dead seedlings that were not planted in 2018).

Table 9: Prior years and natural regeneration SPA

Zone	Total SPA	Prior Planting SPA	Natural SPA
3A	1	0	1
Arroyos 47th Ave SW	6	0	6
AW2	9	0	9
Chicago	8	0	8
EDGS Rose	4	0	4
Maduzia Gap	21	0	21
MF9	1	1	0
PPGS2	42	27	15
PPGS3	34	24	10
Schmitz Blvd Slope	3	0	3
South Ravine Southend	0	0	0
Wolf Tree North	2	1	1

The naturally regenerated and prior year plantings tended to be healthier. The average overall vigor is high. Individual species vigor ranges from high to medium. These seedlings have already survived the first year which is often the most challenging for newly planted seedlings. The ones that survive will typically be the strongest, while the weaker seedlings will most likely have not survived past the first year resulting in a population of second and third year seedlings that are mostly high vigor.

Table 10: Prior year plantings and natural regeneration vigor

Species	Prior Planting	Natural
ABGR	1	1
ACMA3	1	1
ALRU2	None	1
ARME	1	None
CONU4	1	1
COSE16	1	1
FRLA	None	2
FRPU7	1	2
PICOC	2	None
PIMO3	1	None
PISI	1	1
POTR15	None	2
PREM	None	2
PSME	2	1
THPL	2	2
TSHE	2	2

Natural Regeneration

Of the 78 naturally regenerating seedlings that were surveyed, 47% are ACMA3. The prevalence of natural ACMA3 is due to stump sprouting in the Maduzia Gap, PPGS03, and PPGS02 zones that underwent ACMA3 drop-and-leave treatments to open up the canopy. Untreated ACMA3 stumps vigorously sprout in large clumps of new individual stems.

IV. Mortality

Mortality Highlights:
Unless otherwise stated, the mortality analysis discussed in this section is only for seedlings planted in 2018. Douglas-fir (PSME), western redcedar (THPL), and western white pine (PIMO3) suffered the highest mortality rates (20%, 24%, and 25%, respectively). High shrub cover was a strong predictor of mortality. Sites that underwent invasive species removal and site preparation previous to planting have lower mortality rates (average 3.5%) compared to sites where seedlings were planted amid existing ground vegetation (average 17.7%). Shade-tolerant species suffered relatively higher mortality in open-canopy settings (21% vs 10%), most likely due to drier soil moisture conditions during summer (although these surveys didn't measure soil moisture and can't prove that was the main cause of death).

Seedling mortality is a key factor in restoration success. In the mortality section of this Report, we use only transect data (not plot data) because the transects cover a more variable range of conditions. Plots, since they are concentrated in one area, do not capture that variability as well. Seedling mortality ranged from 0% in the Wolf Tree North zone in Discovery Park to 27.5% in PPGS3 in the West Duwamish Green Space zones. This Report investigates some causes of mortality but cannot capture all causes. We discuss other factors that influence mortality at the end of this section.

A. Mortality Overview

Quantifying mortality can help guide planting recommendations in the future. Microsite conditions where a species is planted is as much of a factor in seedling survival as is the simple results of what species or zones experienced higher mortality rates. However, species-level mortality can inform planting guidelines to ensure species that experience high mortality are carefully planted in the most favorable microsites. Note that the surveys are less likely to capture mortality in low-frequency species, unless a species has very high mortality.

Potential Mortality

We attempted to account for the difference in mortality rates given that our surveyed seedling density is consistently lower than the contracted planting density. One possible cause of under-counting is if trees died and surveyors were unable to find the flagging. If this were the case, the mortality would be higher than the survey results indicate. We calculated a potential mortality rate to account for this scenario. The calculation assumes the contracted number of trees was planted, and the discrepancy between the contracted planting amount and the upper 90th percentile of the surveyed SPA is made up by trees that died and the blue-and-white ribbon was not found (
Equation 1). We use the upper 90% confidence interval to provide a conservative estimate of the potential mortality that incorporates the uncertainty within the data. For zones where the 90% confidence interval includes the contracted SPA, we can't claim that our data are likely to be different from the contracted SPA. Thus we do not provide a potential mortality rate for those zones; we don't have enough evidence to support the claim that the surveyed density (and mortality) may be different from the contracted density.

Equation 1: Potential Mortality Rate

Potential Mortality Rate =

$$\frac{\text{Contracted SPA} - \text{Upper Range of } 90^{th} \text{ Percentile Confidence Interval SPA} + \text{Surveyed Mortality}}{\text{Contracted SPA}}$$

Table 11: Potential mortality rate based on uncertainty in data collection, assuming a disproportionate amount of dead trees were not found during surveys.

Park	Zone	Contracted SPA	SPA	Mortality Rate	Potential Mortality Rate
Arroyos Natural Area	Arroyos 47th Ave SW	299	157	13%	35%
Carkeek	3A	297	358	22%	*
Discovery	Wolf Tree North	141	161	0%	*
East Duwamish Green Space	Chicago	176	142	5%	8%
East Duwamish Green Space	EDGS Rose	154	112	3%	*
Schmitz Preserve	Schmitz Blvd Slope	617	1116	2%	*
Seward Park	MF9	107	54	18%	34%
West Duwamish Green Space	Maduzia Gap	229	129	23%	41%
West Duwamish Green Space	PPGS2	227	171	19%	16%[1]
West Duwamish Green Space	PPGS3	232	138	27%	43%
West Duwamish Headwaters	AW2	604	567	6%	*
Yesler Creek Headwaters	South Ravine Southend	No Data	375	2%	No Data

** Contracted SPA is within the 90% confidence interval of the surveyed SPA, so we do not provide a potential mortality rate.*

[1] Potential mortality is lower than surveyed mortality because the contracted SPA is nearly equal to the high range of the 90% confidence interval.

Potential mortality is useful when comparing surveyed mortality with on-site observations. Some zones, particularly in the West Duwamish Greenspace where canopy opening creation took place, appear anecdotally to have high mortality rates. Surveyed mortality is a good sample of actual conditions, though if dead trees are indeed under-counted then potential mortality can help explain the discrepancy.

Surveyed Mortality

We rely on surveyed mortality for data analysis. See

Table 2 for vigor definitions.

Table 12: Species mortality, vigor, and cover conditions in all transect data for 2018 planted seedlings.

Species	Total Surveyed	Total Dead Surveyed	Mortality	Vigor	Overstory	Tall Shrub	Short Shrub
ACMA3	3	0	0%	Medium	11-25%	11-25%	11-25%
FRLA	11	0	0%	Medium	26-50%	26-50%	26-50%
PICOC	18	0	0%	Medium	1-10%	0%	11-25%
SASC	2	0	0%	Medium	51-75%	1-10%	11-25%
TABR2	9	0	0%	Medium	51-75%	11-25%	11-25%
FRPU7	94	1	1%	High	26-50%	1-10%	11-25%
ALRU2	45	2	4%	Medium	1-10%	0%	11-25%
CONU4	18	1	6%	Medium	51-75%	1-10%	26-50%
ABGR	166	10	6%	High	26-50%	1-10%	26-50%
ARME	13	1	8%	Low	0%	1-10%	26-50%
PISI	70	6	9%	Medium	11-25%	11-25%	26-50%
COSE16	7	1	14%	Low	1-10%	1-10%	11-25%
TSHE	98	15	15%	Medium	26-50%	1-10%	26-50%
PSME	241	47	20%	Medium	11-25%	1-10%	11-25%
THPL	153	37	24%	Low	26-50%	11-25%	26-50%
PIMO3	12	3	25%	Low	1-10%	0%	11-25%

Table 12 shows the mortality of all seedlings aggregated at the species level. Mortality ranges from 0% to 25% with PSME, THPL, and PIMO3 representing the three species with the highest mortality. While PSME and THPL have a large sample size, with PSME being the most observed species and THPL being the third most observed, PIMO3 is one of the lowest, with 12 observations in a single zone (Schmitz Blvd Slope). Further analysis in this report investigates factors that influenced mortality in PSME and THPL. PIMO3 is susceptible to white pine blister rust (WPBR), a non-native fungus. While commercially-purchased PIMO3 seedlings are WPBR-resistant, planting stock typically originates from rocky mountain or higher-elevation seed sources, that may be less-well-adapted to lower elevations.

B. Canopy Closure and Mortality

Light is an important factor in seedling survival. Overstory canopy closure and shrub cover both play a role in light that is available to seedlings, and the subsequent seedling survival. Some tree species are more tolerant of shade than others. Both overstory and shrub cover were assigned a percent cover class: 0%, 1-10%, 11-25%, 26-50%, 51-75%. 76-100%.

Overstory Canopy Closure

Table 13 shows the mortality rate of each zone for all surveyed seedlings planted in 2018 and the average canopy closure range of the dead seedlings for that zone.

Table 13: Mortality by canopy closure

Zone	Mortality	% Canopy Closure Range
Wolf Tree North	0.0%	51-75%
South Ravine Southend	1.6%	51-75%
Schmitz Blvd Slope	2.4%	11-25%
EDGS Rose	2.7%	1-10%
Chicago	5.1%	1-10%
AW2	5.6%	0%
Arroyos 47th Ave SW	13.5%	76-100%
MF9	18.2%	26-50%
PPGS2	19.1%	11-25%
3A	22.5%	26-50%
Maduzia Gap	22.8%	11-25%
PPGS3	27.5%	26-50%

We first tested the relationship between overstory canopy closure and seedling mortality without consideration of species shade tolerance. We found no strong relationship, confirming that shade tolerance is an important factor in seedling survival and canopy closure, described later in this section.

Shrub Cover

Shrub cover is actually all non-tree vegetative cover that includes shrubs, forbs, grasses, but for simplicity is referred to as “shrubs.” Short shrub cover includes vegetation less than 6 feet tall, and tall shrub cover is 6 feet tall and taller. We did not investigate species composition; we were more interested in the light environment than the species richness of the sites. Table 14 shows the zone average tall and short shrub value for only the dead seedlings, and mortality rate averaged at the zone level. Tall shrub cover classes ranged from 0% to 25%. Short shrub cover ranges from 10% to 75%. Chart 1 and Chart 2below shows the trend lines and R^2 for the tall and short shrub covers. The R^2 for both tall and short shrub cover is about 0.29 which suggests that both have a weak but consistent impact on the mortality of seedlings.

Table 14: Tall and short shrub mortality

Zone	Mortality	Tall Shrub Value	Short Shrub Value
Wolf Tree North	0.0%	10-25%	10-25%
South Ravine Southend	1.6%	0%	1-10%
Schmitz Blvd Slope	2.4%	0%	10-25%
EDGS Rose	2.7%	0%	26-50%
Chicago	5.1%	10-25%	26-50%
AW2	5.6%	1-10%	10-25%
Arroyos 47th Ave SW	13.5%	1-10%	26-50%
MF9	18.2%	10-25%	10-25%
PPGS2	19.1%	10-25%	51-75%
3A	22.5%	1-10%	26-50%
Maduzia Gap	22.8%	10-25%	26-50%
PPGS3	27.5%	10-25%	26-50%

For the sake of simplicity the charts use a 0 through 5 system to show the canopy closure and shrub cover percentages. The cover class is depicted on y-axis of the following charts

Table 15: cover percentage and class number

Cover percentage	Cover Class
0%	0
1-10%	1
11-25%	2
26-50%	3
51-75%	4
76-100%	5

Chart 1: Tall shrub mortality scatterplot

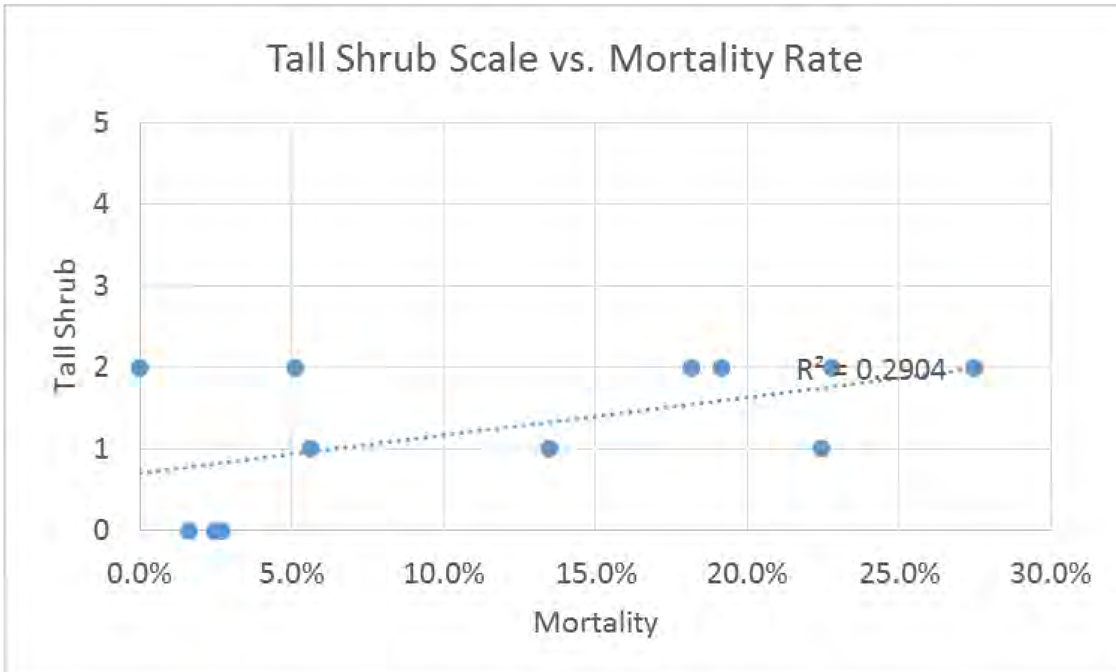
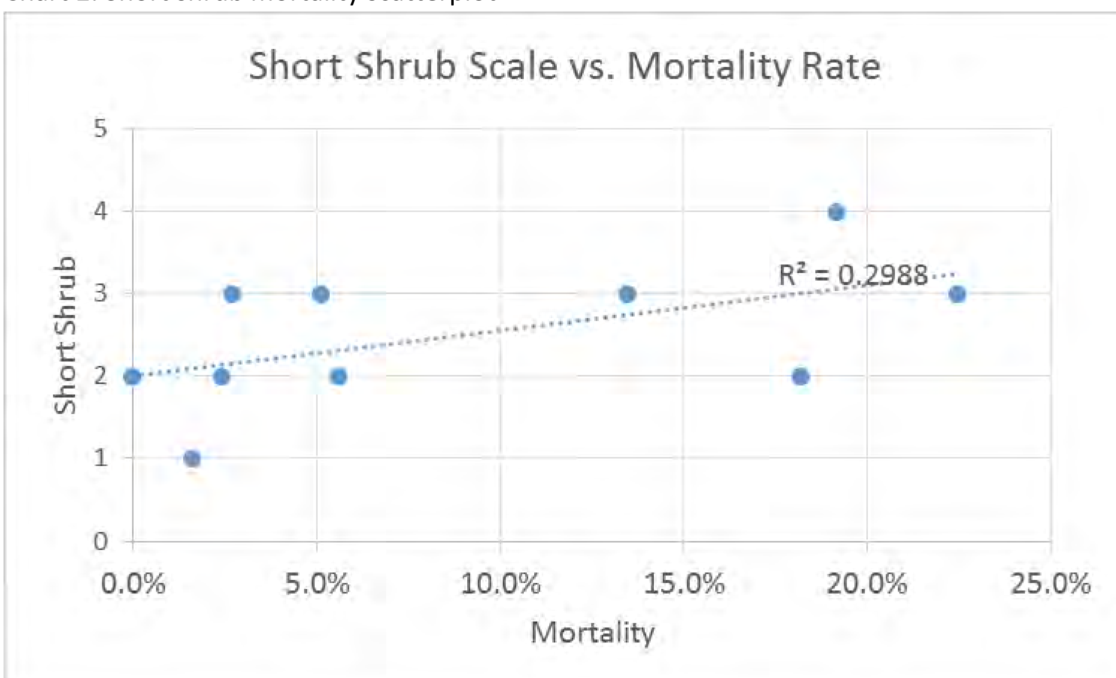


Chart 2: Short shrub mortality scatterplot



Shrub cover percentages include both native and Invasive shrub, though invasive shrub cover was low throughout all survey data. The impacts of shrub cover relates to light competition (and possible water and nutrient competition but our survey didn't measure those factors) regardless of native, non-native, or invasive status.

Combined Canopy Closure and Shrub Cover

When directly comparing mortality to canopy closure and shrub factors individually, there are weak correlations, which suggests that the cause of mortality is most likely a combination of canopy closure, shrub cover, and potentially other factors. To compare the combined effects of canopy closure, tall shrubs, and short shrubs, we conducted a multiple regression of these three factors. A multiple regression is similar to a single linear regression except that it attempts predict the value of a variable based on multiple variables instead of just one. The R^2 for this multiple regression is 0.47 which indicates moderate correlation due to these three factors.

Canopy closure and shrub cover are important variables when assessing seedling mortality, but often do not stand out as primary causes of mortality since different seedling species are influenced by these as well as several other factors. A good example is in zones PPGS2, PPGS3, and Maduzia Gap. These areas experienced some of the highest mortality rates. Although many shade tolerant THPL and TSHE were planted in areas of greater canopy closure, much of these zones were also covered with thick patches of trailing blackberry which was tangling around and choking many seedlings. While the canopy structure was appropriate for the seedling, the shrub cover was not.

Shade Tolerance and Mortality

Table 16: Species shade tolerance

Species	Tolerance	Species	Tolerance
ACMA3	Intolerant	**ABGR**	Tolerant
ALRU2	Intolerant	**ARME**	Tolerant
CONU4	Intolerant	**FRPU7**	Tolerant
COSE16	Intolerant	**PISI**	Tolerant
FRLA	Intolerant	**TABR2**	Tolerant
PICOC	Intolerant	**THPL**	Tolerant
PIMO3	Intolerant	**TSHE**	Tolerant
POTR15	Intolerant		
PSME	Intolerant		
PREM	Intolerant		
SASC	Intolerant		

In general, we expect that shade tolerant species to have lower mortality in areas with higher canopy closure compared to shade intolerant species. When aggregating species into shade tolerant and shade intolerant groups, this expectation does hold. The shade intolerant group of species shows much lower mortality at the higher canopy closure levels than the shade intolerant species.

Table 17: Mortality of shade tolerant and intolerant species.

Canopy Closure	Tolerant	Intolerant
0%	9%	5%
1-10%	21%	14%
11-25%	7%	21%
26-50%	13%	18%
51-75%	9%	21%
76-100%	10%	37%

Table 17 shows how as the canopy closure increases, the mortality of shade intolerant species also increases. It also shows how as the canopy closure increases, the mortality of shade tolerant species does not substantially change. While shade intolerant species are starved for light and die beneath a light-deficient closed canopy, shade intolerant species can survive in light rich environments. The shade intolerant species exhibit the ability to survive in a wider range of light environments compared to shade intolerant species. Shade tolerant species may not grow vigorously under a dense canopy, but they often persist.

Table 18: Mortality of shade tolerant seedlings by zone

Zone	Mortality	Canopy Closure	Tall Shrub	Short Shrub
Schmitz Blvd Slope	0%	0%	0%	0%
Arroyos 47th Ave SW	3%	76-100%	0%	51-75%
South Revine Southend	2%	51-75%	0%	1-10%
3A	10%	76-100%	11-25%	26-50%
AW2	6%	1-10%	1-10%	11-25%
PPGS2	23%	11-25%	11-25%	51-75%
EDGS Rose	5%	1-10%	0%	26-50%
PPGS3	23%	51-75%	11-25%	11-25%
Maduzia Gap	24%	11-25%	11-25%	26-50%
Chicago	6%	1-10%	11-25%	26-50%
MF9	17%	51-75%	26-50%	26-50%
Wolf Tree North	0%	0%	0%	0%

Table 19: Mortality of shade intolerant seedlings by zone

Zone	Mortality	Canopy Closure	Tall Shrub	Short Shrub
Schmitz Blvd Slope	4%	11-25%	0%	11-25%
Arroyos 47th Ave SW	33%	76-100%	1-10%	11-25%
South Revine Southend	0%	0%	0%	0%
3A	32%	26-50%	1-10%	26-50%
AW2	5%	0%	1-10%	1-10%
PPGS2	4%	1-10%	0%	76-100%
EDGS Rose	0%	0%	0%	0%
PPGS3	38%	26-50%	1-10%	51-75%
Maduzia Gap	19%	11-25%	1-10%	51-75%
Chicago	0%	0%	0%	0%
MF9	22%	11-25%	11-25%	1-10%
Wolf Tree North	0%	0%	0%	0%

Table 18 and Table 19 show the mortality of shade tolerant and intolerant seedlings by zone respectively. The canopy closure and shrub cover percentages are the average cover surveyed for only the dead seedlings in the zone, not the average for all seedling in the zone in order to show in which closure levels dead seedlings were found.

Shade tolerant mortality ranged from 0% to 24% while shade intolerant mortality ranged from 0% - 38%. Chart 3 and Chart 4 show the mortality of shade tolerant and intolerant seedling graphed against the canopy closure and shrub cover classes (see Table 15 for definitions). For shade tolerant seedlings, all trend lines show a positive trend which indicates that as percent cover of the three categories increase, seedling mortality increases. Looking at the R^2 values, the short and tall shrubs show a weak to moderate correlation to mortality with R^2 of .26 and .63 respectively. The R^2 for canopy closure is .08 which indicates very little correlation between canopy closure and mortality. It is important to recognize that these trend lines show a single linear relationship, and do not account for interactions between other mortality factors.

Shade intolerant mortality shows similar trends for tall and short shrubs, and the R^2 for canopy closure is much higher at .77, suggesting a moderate to strong correlation between canopy closure and seedling mortality.

Chart 3: Shade tolerant mortality for each zone.

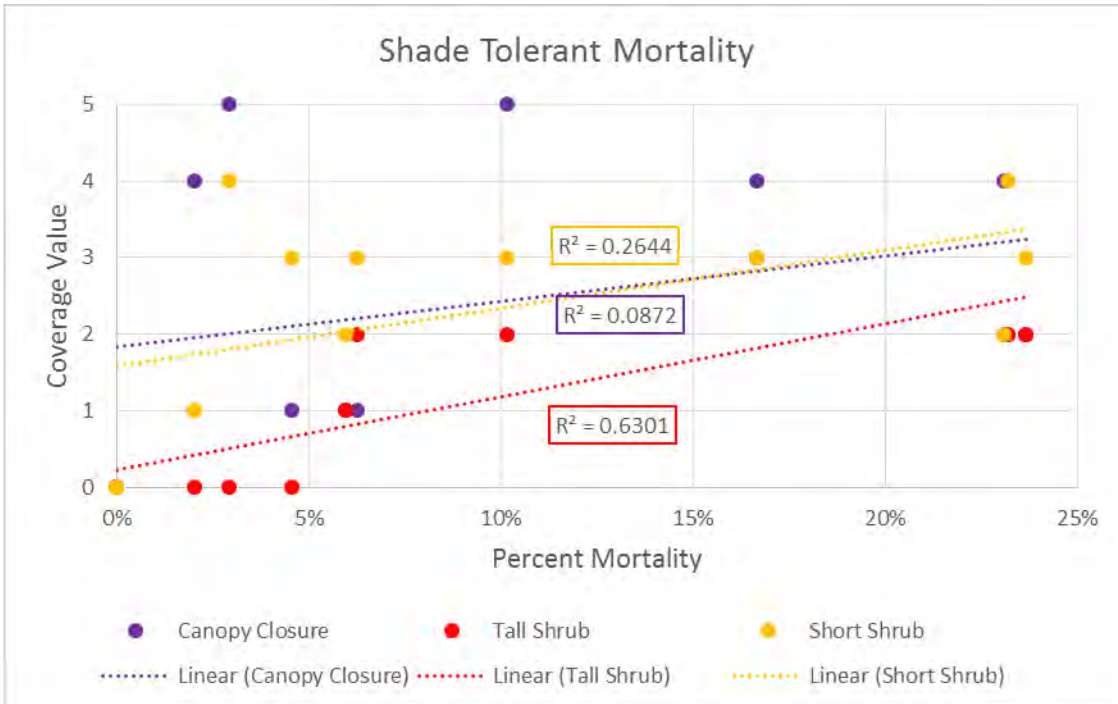
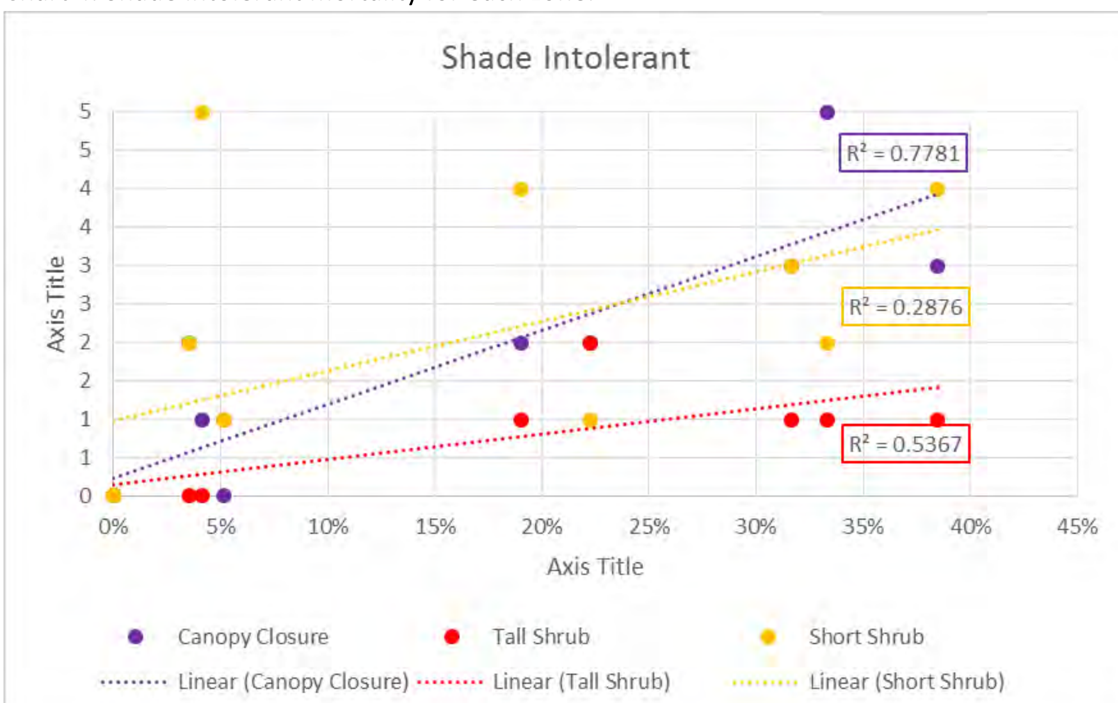


Chart 4: Shade intolerant mortality for each zone.



Three zones in which seedling mortality is high are PPGS02, PPGS03 and Maduzia Gap. These three zones provide a good example for how multiple factors that influence seedling mortality. These three zones have very high levels of trailing blackberry. Trailing blackberry tends to tangle around seedlings and force them horizontal, increasing seedling mortality. While this impacts both shade tolerant and shade intolerant seedlings alike, shade tolerant species are often slower growing and have a lower likelihood of outgrowing the trailing blackberry in their first year or two after planting which can cause a large amount of mortality in shade tolerant seedlings in areas where canopy closure and shrub conditions are otherwise suitable. Open overstory canopies allow more intense sun exposure to the ground, which dries out soil. Shade tolerant species often have higher soil moisture requirements, and may not survive as well.

Canopy Gap Creation and Seedling Mortality

For all seedlings planted in 2018, shade tolerant species surveyed with a canopy closure of 1 to 10% have a high mortality (21%), higher than the mortality of shade tolerant species at other shade canopy closure levels; and is 50% higher than mortality of shade intolerant species under canopy closure of 1-10% (See Table 17). The majority of the dead shade tolerant seedlings under canopy closure of 1-10% are found in the zones in which canopy gaps were created. Some of the mortality may be resulting from a light environment unsuitable to the shade tolerant seedling species, but some of it also may be due to the increase shrub growth outcompeting and killing the seedlings, since they cannot grow as quickly. Soil moisture may be another factor.

Table 20: Shade tolerant vs. intolerant seedling mortality in created canopy gaps.

Canopy Closure	Tolerant	Intolerant
0%	22%	0%
1-10%	29%	16%
11-25%	13%	26%
26-50%	24%	44%
51-75%	22%	13%
76-100%	32%	22%

While 80% of the dead shade tolerant seedling under a canopy closure of 0-25% were found in the zones with canopy gap creation, only 30% of the dead shade intolerant seedling under the same canopy closure range were found in the zones with canopy gap creation. The lower mortality rate of shade intolerant species in the canopy gaps can, at least in part, be attributed to their ability to thrive in light rich environments with a higher drought tolerance, allowing them to compete with nearby shrubs.

While these surveys did not quantify soil moisture, the open canopies increase solar radiance and likely dried out the soils. Shade-tolerant species usually have lower drought tolerance, and the high mortality rate may be due to low soil moisture.

C. Site Preparation and Mortality

The level of mortality may also be related to the type of restoration site that is being planted. Planting zones seemed to fall into two categories: prepared sites or under-planted sites. The prepared sites are areas that recently underwent invasive species removal with the intent to establish a cohort of overstory tree species, primarily conifers. The under-planted zones are zones with an established overstory, but planting took place with the goal of establishing a new cohort to either help convert a broadleaf-dominated overstory to a conifer overstory, or to develop a multi-tier forest structure below a dominant conifer canopy.

The data suggest a clear distinction between the two types of sites. With the exception of Wolf Tree North, the mortality of all the under-planted zones exceeded that of the prepared zones. PPGS02, PPGS03, and Maduzia Gap did have some canopy openings created by cutting AMCA and ALRU2, with the intention of replanting the newly created gaps, but seedling density was no higher in these openings than in non-cut areas. These three zones where gaps were created will still be counted as under-planted sites since the gap creation was limited, shrub removal was not conducted, and planting was not exclusive to the created gaps.

Table 21: Zone mortality by planting zone type

Zone	Mortality	Site Type
Wolf Tree North	0.0%	Under-plant
Arroyos 47th Ave SW	13.5%	Under-plant
MF9	18.2%	Under-plant
PPGS2	19.1%	Under-plant
3A	22.5%	Under-plant
Maduzia Gap	22.8%	Under-plant
PPGS3	27.5%	Under-plant
South Ravine Southend	1.6%	Prepared
Schmitz Blvd Slope	2.4%	Prepared
EDGS Rose	2.7%	Prepared
Chicago	5.1%	Prepared
AW2	5.6%	Prepared

The under-planted zones average 17.6% mortality, while the prepared zones average 3.5% mortality. Prepared sites tend to have much more open canopies, but were also cleared of shrubs before planting. After planting, seedlings were given a thick ring of mulch to help prevent new shrub growth from competing with new seedlings. Although the intensity of site preparation varied among the prepared sites, the substantial decrease in mortality between unprepared and prepared sites suggests that site preparation of any kind increases the chances of seedling survival. However, due to variations in terrain and vegetation conditions across the zones, conducting preparation activities is not always possible or appropriate.

D. Other Mortality Factors Outside the Scope of This Report

In addition to light competition, other factors affect mortality include soil, aspect, summer drought, quality of seedling stock, and planting quality. For example, south facing slopes receive more sun and heat exposure which can stress species that need high soil moisture such as TSHE, while benefitting shade intolerant species such as PSME. Soils can also impact seedling survival. For example, ARME prefers loose sandy soils, so ARME planted on compacted or clay-dominated soils have a lower likelihood of survival. Seedling stock and planting technique are also critical factors. Procuring good quality seedlings from stock that is well-suited to the planting sites, storing them properly, and planting them correctly can significantly reduce the mortality rates of seedlings. Mulching can improve soil moisture conditions. Even placing pieces of woody debris on the south-facing side of a seedling can help reduce solar radiance and evaporation at planting site and increases soil moisture retention.

V. High Density Planting Areas

High-Density Planting Highlights:
Over-planting can lead to stressed trees and high mortality starting in 10 to 15 years. Four sites have seedling densities that exceed 350 SPA (Schmitz Blvd Slope, South Ravine Southend, AW2, and 3A). While high-density planting can insure against high seedling mortality and limit invasive species proliferation, long-term impacts to forest health are likely if tree density remains high (greater than around 250 SPA in 10 to 15 years).

High seedling density can lead to competitive mortality and unhealthy forest conditions in the future. Competitive mortality occurs when adjacent trees are fighting for light, water, and nutrients, and some are not able to survive. Surviving trees are stressed and are more susceptible to insect, disease, and drought, leading to higher mortality. The seedling planting density varies greatly across the surveyed zones. The desired seedling density depends mainly on the density of existing overstory or understory trees already present in the zone.

For this Report, we define high density areas as zones where seedling density exceeds 350 SPA. Four sites exceed 350 SPA as shown in Table 22. Three out of the four are prepared restoration sites, meaning that they were cleared of invasive shrubs to open up large contiguous areas of planting space.

Table 22: High planting density zones

Zone	Total SPA	Acres	Site Type
Schmitz Blvd Slope	1116	0.65	Prepared
South Ravine Southend	375	1.2	Prepared
AW2	567	1.25	Prepared
3A	358	5.36	Under-planted

The prepared sites have substantial available planting space since nearly all of the ground has been made available for planting through the removal of invasive shrubs (where possible, native shrubs were retained). Planting at moderate or high density can help offset losses from seedling mortality, but it can also stifle the growth of otherwise healthy seedlings due to very high density. We do not expect to see density-related mortality at this stage, but as the seedlings develop and compete with each other, we forecast slower growth and higher mortality than lower-density sites.

High-density planting can be a part of a management strategy that insures against high seedling mortality and creates shaded understory conditions to limit invasive species proliferation. However, thinning high-density planting sites would be important once seedlings canopies touch (signifying the start of inter-tree competition). Cutting the least vigorous seedlings approximately 10 to 15 years after planting would allow the vigorous trees to flourish. Thin to retain around 200 to 250 SPA of healthy trees about 10 to 15 years after planting.

VI. Live Seedling Success

Live Seedling Success Highlights:
Seedling height and vigor typically did not correlate with canopy cover. Only shade-intolerant species (PSME, PISI) showed statistical correlations between increased height and more open canopies. Variability in live seedling success in the first year following planting may be due to microsite conditions and seedling stock rather than canopy or shrub cover. We suspect height and vigor differences will be more pronounced in subsequent years.

Among the live seedlings, height and vigor were measured to indicate seedling success. We further divided the data by species to help assess success.

Canopy closure is a critical factor for determining the density and species of planted seedlings, but also is important to the survival of the planted seedlings. Some species such as PSME, ALRU2, and ARME grow and survive better in open canopies. The below maps show examples of zones with canopy closures of 0% through 75%. No surveyed zone yielded an average canopy closure of 76-100%. In general, the more open a canopy, the more available planting space there is below it.

Table 23: Canopy closure examples

Zone	Canopy Closure	SPA	Mortality
AW2	0%	567	5.6%
Schmitz Blvd Slope	1-10%	1116	2.4%
EDGS Chicago	11-25%	141	5.1%
EDGS Rose	26-50%	111	2.7%
Wolf Tree North	51-75%	161	0%

Figure 2: 0% canopy closure

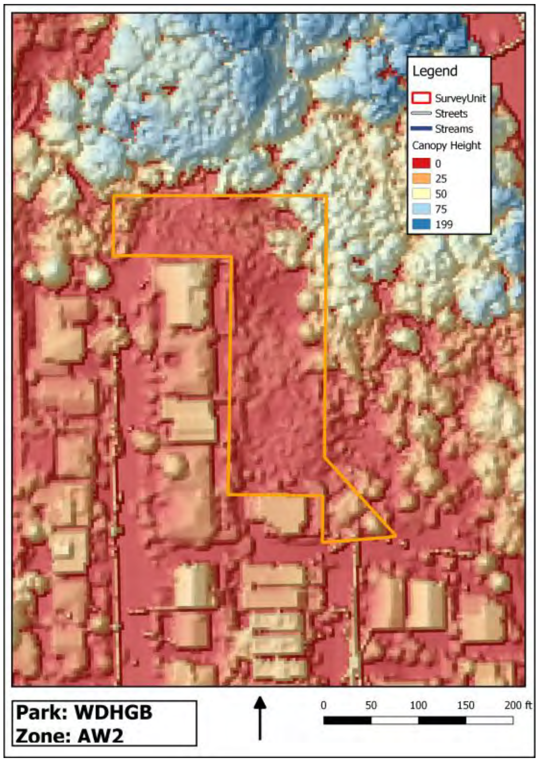


Figure 3: 1-10% canopy closure

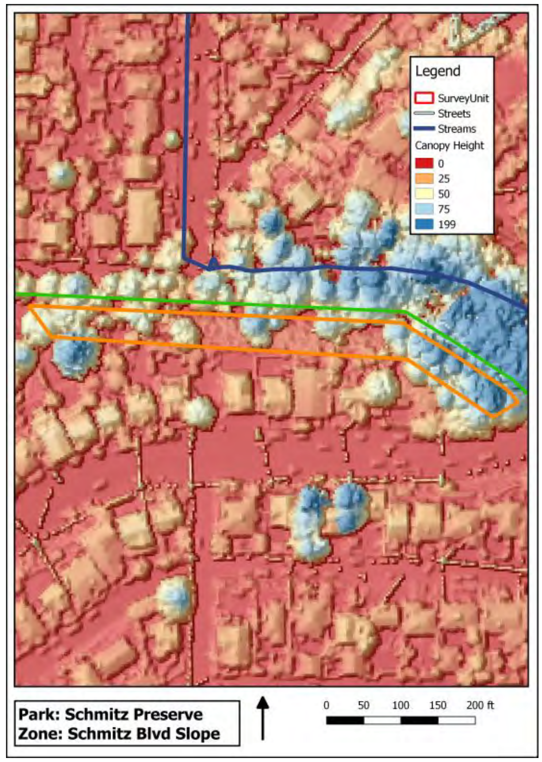


Figure 4: 11-25% canopy closure

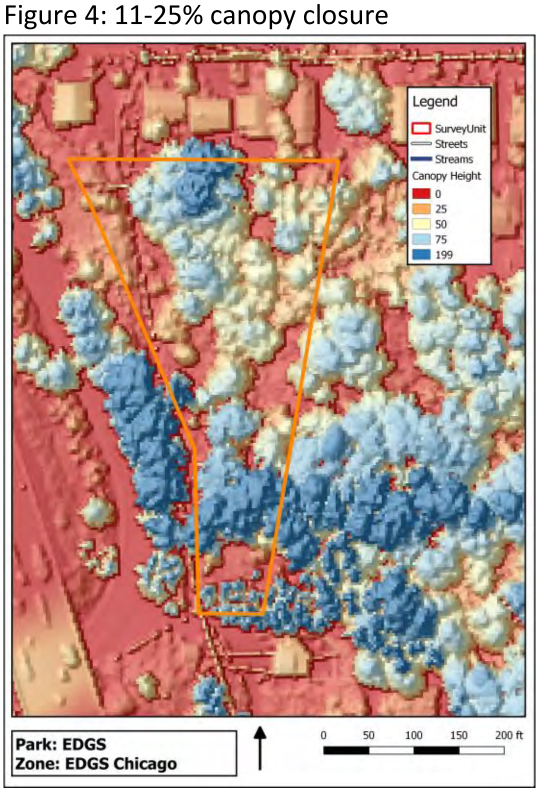


Figure 5: 26-50% canopy closure

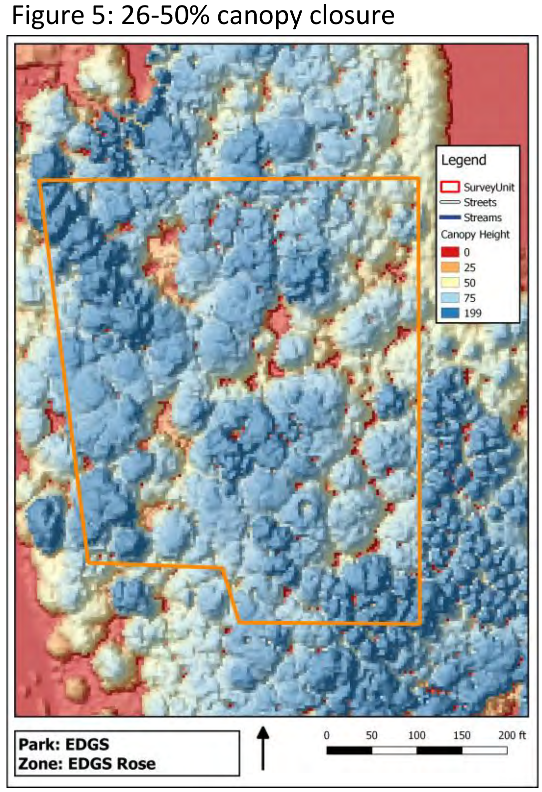
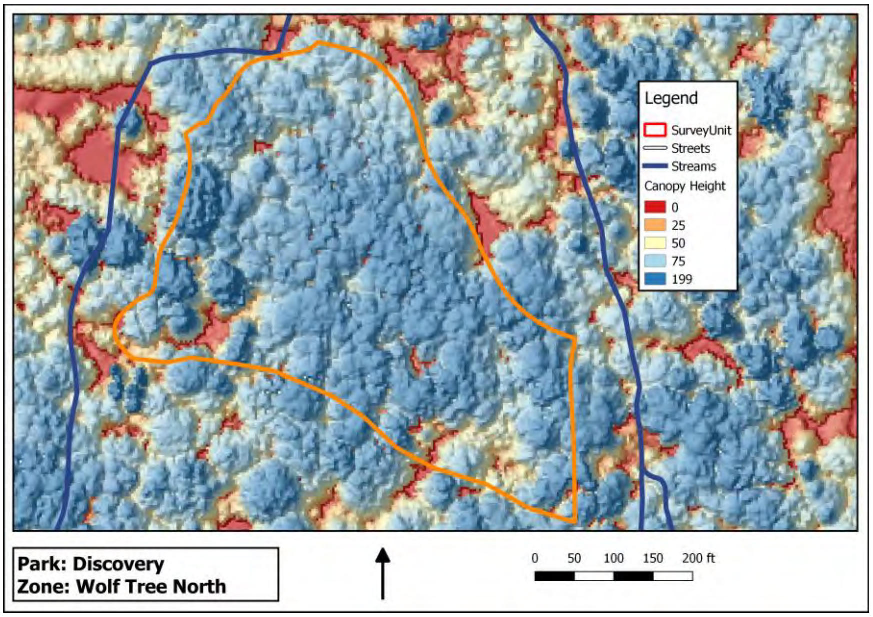


Figure 6: 51-75% canopy closure



A. Seedling Height, Vigor, and Canopy Closure

In total, 968 seedlings planted in 2018 were surveyed across all zones and transects, of which 848 were alive at the time of data collection. We tested the relationship between seedling height and canopy closure, hypothesizing that seedling height would be shorter under closed canopies. However, we found no correlation (the R^2 for the canopy closure to height relationship is .003). We suspect that tree height growth in the first year following planting is minimal, and height of seedling stock at time of planting is a bigger driver of height than canopy closure. Future measurements may show a relationship between height and canopy closure.

Similarly, we tested the relationship between seedling vigor and canopy closure, hypothesizing that seedlings would be more vigorous under open canopies. However, we found no correlation (the R^2 for the canopy closure to vigor relationship is .047). We assume seedlings exhibited high vigor when planted.

Table 24 provides the R^2 values for the relationships between canopy closure, height, and vigor for each species. In total, 19 different species are represented in the data, but only seven species had a large enough sample size of at least 30 to calculate a reliable R^2. The highest R^2 values among these species are PISI, with a height R^2 of 0.29, and ALRU2's vigor R^2 at 0.50. These two results indicate moderate correlation, while the remaining R^2 results are below 0.10, and do not provide evidence for correlation.

Table 24: Canopy closure vs height and vigor R^2 by species

Species	Sample Size	Height R^2	Vigor R^2
ABGR	157	0.041	0.023
ALRU2	43	0.055	0.504
FRPU7	93	0.000	0.066
PISI	64	0.299	0.002
PSME	195	0.011	0.255
THPL	117	0.024	0.002
TSHE	84	0.005	0.009

Thus far, only linear regression analyses have been conducted in order to compare site conditions with seedling growth and survival. We hypothesize that species, canopy closure and height or vigor interact in more complicated ways.

B. ANOVA Canopy Analysis

Height vs. Canopy Closure

In addition to conducting a linear regression analysis, the data were also analyzed using a one-sided analysis of variance (ANOVA) test comparing canopy closure and height. The first ANOVA was conducted for all live seedlings planted in 2018, finding a weak relationship (P-value of .08) that suggests as canopy closure increases, height decreases. In other words: a more open canopy may influence seedling height growth in the first year.

A similar ANOVA test for disaggregated species yielded varied results. Only species with at least 30 seedlings surveyed were included in the individual species analysis to ensure adequate sample size. Results were generally inconclusive, though two sun-dependent species showed correlations between taller heights and more open canopy closure: PISI, the only statistically significant result (P-value of .0002), and PSME showed a weak correlation (p-value of .07). These results suggest light environments are not a strong predictor of height in a seedling's first year.

Table 25: ANOVA analysis summary comparing height and canopy cover for seen common species.

Species	P-value
ABGR	0.11
ALRU2	0.28
FRPU7	0.98
PISI	0.0002
PSME	0.07
THPL	0.14
TSHE	0.66
7 Species	0.09

Overall, the ANOVA tests suggest that seedling height is not significantly related to canopy closure. Initial height of the planting stock likely influence the height data collected after the initial growing season. Additionally, different planting projects may have sourced seedlings from different nurseries and provenance. Finally, this ANOVA analysis does not account for shrub cover or other environmental reasons why seedlings may have grown more or less.

Shade Tolerant vs. Intolerant

ANOVA tests were also conducted for seedling species grouped into shade tolerant and intolerant. The shade intolerant species returned a P-value of .058, suggesting a weak relationship between canopy closure and seedling height. The ANOVA for shade tolerant species returned a P-value of .21, suggesting little to no relationship between canopy closure and seedling height in the first year following planting. Comparing these two results to each other suggests that shade intolerant species are more influenced by different levels of canopy closure than shade tolerant species. While shade tolerant species may have greater ability to survive across the range of canopy closure classes, shade intolerant species have the ability to grow larger, faster, when in more favorable environments.

VII. Permanent Plots

Permanent Plot Highlights:
Permanent plots showed similar density and mortality results compared to the transect data, typically within about 5% of the transect averages. The most powerful value of permanent plots will be future repeat measurements to assess longer-term seedling survival.

A set of 25 permanent plots were installed. These plots are monumented with rebar and GPSed so follow-up surveys to the plots can be conducted in future years in order to compare survival and growth metrics. Table 26 below compares the surveyed seedlings at the species level of plots and transects. All seedlings are included, not just seedlings planted in 2018. The comparisons are given at the aggregate level and are not zone specific.

Table 26: Transect vs. plot results at species level for all seedlings (not limited to 2018 planting season).

	Plots			Transects		
Species	**Total SPA**	**Live SPA**	**Dead SPA**	**Total SPA**	**Live SPA**	**Dead SPA**
ABGR	31	28	3	39	37	2
ACMA	10	10	0	9	9	0
ALRU2	10	9	1	10	10	0
ARME	5	4	1	3	3	0
CONU4	3	3	0	6	6	0
COSE16	2	2	0	2	2	0
FRLA	3	3	0	3	3	0
FRPU7	26	25	1	21	20	0
PICO	0	0	0	4	4	0
PIMO3	0	0	0	3	2	1
PISI	15	14	2	16	15	1
POTR15	0	0	0	1	1	0
PREM	2	2	0	1	1	0
PSME	65	57	9	55	45	10
SALUL	1	1	0	0	0	0
SASC	3	3	0	0	0	0
TABR2	2	2	0	2	2	0
THPL	33	24	9	34	26	8
TSHE	10	9	2	23	19	3
Total:	**223**	**195**	**28**	**233**	**206**	**27**

Table 27: Transect vs. plot results summary

	Number of Units	Total Area (acres)	Total Count	Live Count	Dead Count	Total SPA	Live SPA	Dead SPA
Transects:	86	4.7	1102	974	128	233	206	27
Plots:	24	2.4	536	469	67	223	195	28
					Difference:	10	11	-1
					% Difference:	4%	5%	-2%

When comparing the transect data to the plot data, the total SPA, live SPA, and dead SPA are all within 5% difference of each other. In total, the transects covered 4.7 acres of area across all surveyed zones, while the plots covered 2.4 acres, though the proportional results in terms of live and dead seedling SPA compares to total SPA are very similar when comparing plots to transects.

Permanent plot data supported the results in this Report, but the greatest power of permanent plots is repeat measurements over time and the ability to track longer-term seedling success. Since plot data methods included recording azimuth and distance to individual seedlings, we can track survival for individual seedlings, building a very helpful dataset into the future. We recommend re-measurements at two years and five years, though re-measuring any time in the first five years will provide useful results.

VIII. Recommendations for Future Planting Projects

1) Plant shade-tolerant species in sites that are likely to retain soil moisture during summer drought. Results indicate higher mortality rates for shade-tolerant species in more open canopy settings may be due to drought-related mortality.
2) Limit planting projects in areas that have high shrub cover. While current seedling placement takes in to account overstory canopy closure, shrub cover also limits seedlings' success. Alternatively, cut back competing shrubs, even native species, around seedlings.
3) Prioritize planting projects in areas that have undergone site preparation in the form of invasive plant removal. Mortality rates are lower in these sites compared to sites where shrub removal did not take place – even if the shrubs are native shrubs.
4) Re-measurement of sites, particularly permanent plots, will help inform longer-term seedling survival.

IX. Appendix A: Flagging Color

X. Appendix B: Zone Summary Tables

Schmitz Blvd Slope species mix

Species	Surveyed Total SPA	Surveyed Live SPA	Surveyed Dead SPA[1]	Contracted Planting SPA[2]	Surveyed vs Contracted SPA[3]
ABGR	9	9	0	0	9
ALRU2	182	182	0	62	120
COSE16	9	9	0	0	9
FRPU7	290	290	0	154	136
PICO	163	163	0	77	86
PSME	299	299	0	154	145
PIMO3	27	0	27	31	-4
TSHE	54	54	0	62	-8

[1] Dead trees that have blue-and-white ribbon indicating they were planted in 2018.

[2] Planting densities specified in planting contracts

[3] Difference between contracted planting densities and the measured total SPA

AW2 species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	82	82	0	40	42
ACMA	9	9	0	24	-15
ALRU2	73	73	0	40	33
ARME	50	45	5	20	30
FRLA	9	9	0	24	-15
FRPU7	50	50	0	40	10
PISI	23	23	0	20	3
PSME	168	154	14	160	8
SASC	5	5	0	48	-43
THPL	50	41	9	60	-10
TSHE	45	41	5	32	13

PPGS2 species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	29	29	0	63	-34
CONU4	4	4	0	1	3
COSE16	7	7	0	0	7
FRPU7	7	5	2	19	-12
PISI	22	20	2	19	3
PSME	27	25	2	19	8
TABR2	5	5	0	3	2
THPL	29	13	16	58	-29
TSHE	33	24	9	19	14

PPGS3 species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	33	29	5	63	-30
CONU4	15	15	0	1	14
FRPU7	8	8	0	19	-11
PISI	12	8	5	19	-7
PSME	24	9	15	19	5
TABR2	6	6	0	3	3
THPL	18	9	9	58	-40
TSHE	21	17	5	19	2

Maduzia Gap species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	31	25	6	63	-32
ARME	2	2	0	0	2
CONU4	3	2	1	1	2
FRPU7	3	3	0	5	-2
PISI	10	9	1	19	-9
PSME	20	17	3	19	1
THPL	36	20	16	58	-22
TSHE	23	20	2	19	4

EDGS Rose species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	21	21	0	34	-13
ACMA	3	3	0	4	-4
ALRU2	9	9	0	4	5
CONU4	6	6	0	2	4
PISI	9	9	0	21	-12
PSME	15	15	0	17	-2
THPL	21	21	0	38	-17
TSHE	15	12	3	25	-10
FRPU7	0	0	0	9	-9

South Ravine Southend species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	133	133	0	No Records	N/A
FRPU7	12	12	0	No Records	N/A
PISI	6	6	0	No Records	N/A
PSME	79	79	0	No Records	N/A
THPL	91	91	0	No Records	N/A
TSHE	54	48	6	No Records	N/A

Arroyos 47th Ave SW species mix

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	24	24	0	43	-19
ALRU2	18	12	6	11	7
FRPU7	36	36	0	87	-51
PSME	36	24	12	43	-7
TABR2	6	6	0	0	0
THPL	27	27	0	43	-16
TSHE	9	6	3	22	-13
ABGR	24	24	0	43	-19
PREM	0	0	0	43	-43
ARME	0	0	0	7	-7

EDGS Chicago species mix

Species	Total SPA	Live SPA	Dead SPA	Planted SPA	SPA Difference
ABGR	33	33	0	38	-5
CONU4	4	4	0	2	2
FRPU7	7	7	0	9	-2
PISI	44	40	4	24	20
PSME	18	18	0	19	-1
THPL	25	22	4	43	-18
TSHE	7	7	0	28	-21
ACMA3	0	0	0	8	-8
ALRU2	0	0	0	8	-5

MF9 species mix

Species	Total SPA	Live SPA	Dead SPA	Planted SPA	SPA Difference
THPL	21	16	5	23	-2
PSME	21	18	3	9	12
COSE16	3	0	3	5	-2
TSHE	3	3	0	9	-6
FRPU7	10	10	0	18	-8

<u>Wolf Tree North species mix</u>

Species	Total SPA	Live SPA	Dead SPA	Contracted SPA	SPA Difference
ABGR	20	20	0	10	10
FRLA	20	20	0	23	-3
FRPU7	34	34	0	23	11
PISI	41	41	0	23	18
SASC	2	2	0	12	-10
THPL	41	41	0	47	-6
TSHE	2	2	0	0	0
POTR15	0	0	0	3	-3