SEATTLE PARKS AND RECREATION / GREEN SEATTLE PARTNERSHIP

SEEDLING SURVIVAL ADDENDUM REPORT

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GREEN SEATTLE PARTNERSHIP

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I. Executive Summary

This Addendum Report is the second-year follow-up to the 2018 Seedling Survival Report. The project aimed to capture seedling survival rates and causes at twelve Green Seattle Partnership planting projects installed during the 2017-2018 planting season.

Key Findings

Across all 12 projects, survival fell to 46% in the fall of 2019 (down from a conservative calculation of 83% in fall of 2018). About half the sites had survival between 57% and 69% - which is reasonable, if a little lower than we hoped, given the drought and freeze conditions in 2018 and 2019. The other half of the sites did much worse, with survival ranging from 36% down to only 2%. Seedlings that were alive in 2018, but showed signs of stress, typically did not survive through 2019.

Canopy

Canopy cover significantly influences seedling mortality and height. Sites with more than 50% canopy closure (mostly closed canopies) suffered 74% mortality on average, compared to 37% in sites with canopy closure less than 50%.

- Average canopy cover remained unchanged in 2019 compared to 2018, but plots and transects with high overstory cover experienced higher seedling mortality than plots with low cover.
- Canopy closure weakly correlated with increased mortality in a linear regression ($r^2 = 0.3885$).
- Open canopy cover significantly correlated with taller live seedlings (ANOVA test resulted in $p=0.001$ for all seedlings).

Species

Broadleaf species including red alder, madrone, and Oregon ash had the highest mortality rates (>70%). Western redcedar, western hemlock, and Sitka spruce also had high mortality rates (between 56% and 63%). Douglas-fir and grand fir had better survival, with mortality rates of 49% and 36%, respectively.

Tall and Short Vegetation

Tall vegetation limits seedling height. No relationship was found between seedling mortality and tall or short vegetation.

- Average cover increased compared to 2018 by about 19% for both tall and short vegetation.
- Seedlings can survive within dense vegetative cover – we found no relationship in when looking a linear regression of survival compared to vegetation cover ($r=0.0031$ for tall shrubs).
- An analysis of variance showed a significant relationship between height and tall vegetation cover ($p=0.015$), indicating that tall vegetation limits seedling height. Longer term, we speculate this will likely lead to more mortality.
- Invasive plant cover is low at 11% on average, indicating the invasive plant treatments before and after planting are effective. Invasive cover did correlate with shorter heights ($p<0.001$).

Soils

Soils are an important driver of seedling survival, and more data will help clarify the soil-seedling interactions. Silt and clay soils correlated with high mortality rates, while sandy and loamy soils correlated with lower mortality rates. Results are counter-intuitive; we speculate that the limited sample size and the limited soil profile (only down to 18 inches, rather than several feet) provide an incomplete picture of the role of soil in seedling survival.

- Sandy soils correlated with the lowest average mortality. Sandy soils also have the largest range of mortality for the soil sub-groups. While seedlings planted in sandy clay loam have a mortality rate of 23% (the lowest of all soil types), sandy loam has a mortality of 93%, one of the highest.
- Silty soils showed the highest mortality at 74% and a range of 50% (silty clay) to 100% (silt loam).
- We would expect high mortality on sandy soils that become dry in the summer, but the data show the opposite. Deeper soil pits could reveal compacted hard-pan layers or other features that would explain higher mortality in loamy and silty soils, where we expected better survival.

Management Actions

Management actions before and after planting impact seedling survival. Watering emerged as an important factor in promoting survival.

- Sites that were watered had 26% mortality on average, while un-watered sites had 65% mortality. Watered sites also tended to have mulching and brushing, so it is hard to discern the combined benefits of these seedling maintenance activities versus watering alone.
- Mulching in 2018 continues to benefit seedlings, with mulched seedlings having about 11% better survival than un-mulched sites on average.
- Plots without shrub control before planting experienced higher mortality than plots without shrub control, though the difference was less strong in 2019 compared to 2018. Treatments that took place in summer 2019 probably didn't leave enough time for seedlings to respond sufficiently to be detected in fall 2019 measurements.
- The zones with the lowest mortality (South Ravine Southend, AW2, and Schmitz Slope) had several maintenance activities including brushing, mulching, and watering.

Total seedling density and ecological condition

Overall seeding densities are much healthier when including natural regeneration and seedlings from previous plantings. Three sites have more than 800 seedlings per acre, and a majority are broadleaf species. Six sites had good overall density between 150 and 350 seedlings per acre, with a mix of conifer and broadleaf species. Three sites had low total survivorship less than 50 seedlings per acre, where additional planting may be required; these three sites had dense canopies.

Management Implications

- Ensure there is sufficient open canopy for seedlings to thrive by either cutting canopy gaps or locating plantings in natural canopy openings.
- For future planting projects, reconsider under-planting existing canopies (canopies >50% closure). Plant densely to compensate for high mortality rates (expect ~75% of seedlings to die).
- Canopy gap treatments, while effective and creating favorable light conditions, must be coupled with aggressive vegetation control in the years following planting until trees have exceeded the height of competing vegetation, typically around 5 years.
- Vegetation (including native vegetation) should be cleared within a 3 to 5-foot radius ("cones of light") of seedlings when planted, especially when tall vegetation is present.
- Soil analysis (digging soil pits) could be conducted before planting to help assess what species should be planted and set expectations for seedling survival. Adding more soil data to seedling monitoring will improve SPR's understanding of soil's impact on survival.
- Watering correlates with the highest survivorship. Water where feasible. Where it is not feasible, plan for higher mortality rates and invest in mulching and vegetation control.
- Mulching has a lasting impact on seedling survival; continue to mulch around seedlings.
- Assess overall seedling density and the presence of competing hardwoods. In high density zones (> 400 seedlings per acre), consider thinning out (cutting) seedlings to improve conifer survival.

II. Need for Long-Term Seedling Surveys

Seattle Parks and Recreation (SPR), working with the Green Seattle Partnership (GSP), is committed to implementing successful tree planting projects to improve the quality of Seattle's urban forests. Tracking the success of these projects is an important way to ensure that SPR is achieving their restoration objectives. 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 the surveyed seedling densities to the initial planting densities, and conditions in 2018. This Addendum Report is the follow-up of seedling survival surveys that were conducted and reported on in 2018[1]. Please refer to the 2018 report for site descriptions, methods, and first year results.

III. Methods and Analysis Updates

This Addendum includes a few updates to survey methods and analysis techniques. First, to familiarize readers with the methods without having to reference the 2018 Report: Two systems of field surveys were developed for monitoring: transects were used to sample seedlings and environmental conditions across large planting sites, and permanent plots were used in smaller areas that allow remeasurement of the exact same seedlings year over year. These two different but related data sets allow us to report on mortality, vigor, and height among the surviving trees, and test correlations between seedling survival and several environmental and management factors such as canopy openness, shrub competition, soil texture, site preparation, and other factors related to seedling survival.

Table 1: Sample design in 2019

Park	Zone	Planted Acres	Number of Transects	Number of Permanent Plots	% of acreage surveyed
Arroyos Natural Area	Arroyos 47th Ave SW	2.3	6	2	23%
Carkeek Park	3A	5.3	8	4	16%
West Duwamish GS: Puget Park	Maduzia Gap	8.2	16	0	11%
West Duwamish GS: Puget Park	PPGS2	4.6	10	4	21%
West Duwamish GS: Puget Park	PPGS3	6.3	12	0	10%
Duwamish Head Greenbelt	AW2	1.3	4	2	32%
East Duwamish GS: S Chicago St	Chicago	1.8	4	2	23%
East Duwamish GS: S Chicago St	Rose	2.2	5	1	17%
Seward Park	MF9	4.4	8	4	19%
Schmitz Preserve Park	Schmitz Blvd Slope	0.6	2	0	18%
Yesler Creek Headwaters	South Ravine Southend	1.2	3	1	22%
Discovery Park	Wolf Tree North	4.3	8	4	20%
Totals	**12 zones**	**42.7**	**86**	**24**	**16.7%**

[1] Barenboim, B., Fischer, P., Churchill, D., Ciecko, L., and Yadrick, M. 2018. Seedling Survival Report. Seattle Parks and Recreation and Green Seattle Partnership. https://www.greenseattle.org/wp-content/uploads/2019/02/Seedling-Survey-Report-smaller.pdf

New this year, we added an evaluation of weather, included soil texture data from permanent plots, updated our analysis methods, and expanded discussions on site preparation and site conditions to help contextualize what is happening to the seedlings.

Weather

Weather events, particularly drought and freezes, can stress and kill seedlings. We looked at drought duration and freeze events to qualitatively add context to the trends in survival we are seeing after two years.

Soils

Soil data are lacking in Seattle's urban environment, so surveys at permanent plots included digging an 18" deep soil pit, and soil texture was tested at the bottom of the pit to classify soil conditions at the lower end of rooting depth. Soil pits only occurred for permanent plots because plots are relatively small, and one pit can reasonably categorize soil conditions for all seedlings within that plot. Transects are distributed across large areas and digging soil pits sufficient to categorize conditions across long strings of transects would have been outside of the scope.

Analysis

In the second year of monitoring, two factors have made ascertaining mortality more difficult: 1) dead seedlings quickly fall over and become lost, and 2) as time goes on the blue-and-white flagging that indicated seedlings were planted in 2018 degrades and falls off, is pulled off by animals, or otherwise becomes lost. This limits the accuracy of directly observing dead seedlings and seedlings from the planting group (distinct from natural regeneration or previous planting projects). To work around these difficulties, mortality in this report is calculated based on data from the original 2018 observation of all seedlings with blue-and-white flagging. This assumes that all seedlings planted in spring 2018 retained their flagging through the 2018 growing season until field workers conducted the surveys. Mortality is calculated by subtracting the number of observed live seedlings with blue-and-white flagging in 2019, from the total number of planted seedlings from the 2018 data.

This method still likely overestimates mortality, because live seedlings can lose their blue-and-white flagging. To adjust for this overestimate, in the data analysis stage, some seedlings that did not have blue-and-white flagging were assumed to still be part of the original planting cohort. These seedlings had to meet all of the following criteria: live, have no previous year's flagging, were not recorded as "natural" regeneration (a subjective determination by the field worker used only when seedlings were of a dramatically different growth form than the planted seedling cohort such as very small or very large), 5 feet tall or less (5 feet is the 90th percentile height of live seedlings that were planted in 2018), and not part of a regenerating clump. This added 49 trees to the survey. That is an 8% addition to the 625 live blue-and-white trees that were observed in 2019.

Site Preparation

Site preparation and other restoration actions influence seedling survival. We researched SPR's "CEDAR" database of records of restoration actions at sites with high mortality and low mortality to investigate why seedlings are thriving or dying.

IV. Weather

Weather events and trends, particularly long periods of drought, freezing conditions, and heavy snowfall can increase mortality in recently-planted seedlings. The seedling surveys were not designed to quantitatively address the impacts of weather conditions on seedling survival, but it is important to note these severe weather events and discuss in the potential impacts on seedling survival.

Freeze and Snow

Seedlings are more vulnerable to freeze events. Frozen foliage and roots stress a tree and limit its ability to take up water and photosynthesize once the plant accelerates growth in the spring. Snowfall can be a factor, though snow insulates young trees from freezing temperatures. February 2019 had several freezing days, with temperatures below 20˚F and several inches of snow.

Drought

Most seedlings were planted in early spring (1st quarter and into April) 2018, which is the preferred timeframe because winter and spring rains deliver the moisture that new seedlings need to establish. The summer of 2018 was relatively dry, though not a severe drought. This first summer following planting is critical for seedling establishment. Summer 2019 was relatively moderate; however, winter and spring 2019 (1st and 2nd quarter) were much drier than normal. Most tree growth occurs in the spring, and 2019 included several very hot days with temperatures above 90˚F. Total precipitation was 3.3 inches over April-May-June in 2019, while the long-term average for the same time period is 7.9 inches[2]. The total precipitation deficit relative to long-term averages in the first three quarters of 2019 was 10.3 inches. Combined with the freeze events in early winter 2019, seedlings had a difficult year.

Table 2: The number of days with minimum temperatures below three temperature thresholds, maximum temperatures, and precipitation and snowfall quarterly summaries for the Seattle area in 2018 and 2019 through 3rd quarter.

	Freeze Days - Min Temp[1]			Max Temp[1]	Precipitation[1]	Departure From Average Precipitation[1]	Total New Snow[2]	Max Snow Depth[2]
Quarter	**<30°F**	**<25°F**	**<20°F**	**°F**	**Inches**	**Inches**	**Inches**	**Inches**
Q1 2018	8	2	-	73	11.77	-1.6	1	1
Q2 2018	-	-	-	87	6.26	-0.8	-	-
Q3 2018	-	-	-	91	1.45	-2.0	-	-
Q4 2018	3	-	-	70	12.57	-3.4	-	-
2018 Precipitation:					**32.05**	**-7.83**		
Q1 2019	20	9	7	79	8.22	-5.2	21	7
Q2 2019	-	-	-	94	3.30	-3.8	-	-
Q3 2019	-	-	-	89	2.13	-1.3	-	-
2019 Precipitation Through 3rd Quarter					**13.65**	**-10.26**		

[1] Source (temperature, precipitation): https://www.ncdc.noaa.gov/cdo

[2] Source (snow): https://w2.weather.gov/climate/xmacis.php?wfo=sew

[2] Anthony Arguez, Imke Durre, Scott Applequist, Mike Squires, Russell Vose, Xungang Yin, and Rocky Bilotta (2010). NOAA's U.S. Climate Normals (1981-2010). [indicate subset used]. NOAA National Centers for Environmental Information. DOI:10.7289/V5PN93JP [Accessed 11/11/2019].

V. Seedling Survival Results

Many zones suffered substantial mortality since the last measurements in 2018. The following sub-sections rely on combined data from both transects and permanent plots.

Survival - Zones

Overall mortality of planted seedlings varies considerably across plots, ranging from nearly no mortality in planted seedlings in South Ravine Southend in Yesler Creek, to near total mortality in Arroyos Natural Area's zone Arroyos 47th Ave SW, and Seward Park zone MF9 (Table 3). Table 3 presents two sets of information – first, the total amount of live seedlings that includes seedlings planted in 2018 (indicated by blue-and-white ribbon on the seedlings), plus natural regeneration and seedlings that were planted in other years. Second, Table 3 focuses on seedlings planted in 2018. Additional analysis of total seedling density and ecological condition are in Section VIII: Ecological Condition.

Locating dead seedlings is difficult, especially as time goes on since the seedling died, because it is hard to recover the dead stem. The flagging helps re-located these trees, but the flagging gets covered by leaf fall and ground vegetation. So, observed mortality in 2019 is unreliable, since we are likely missing dead trees. To correct for this, we used the 2018 data for all seedlings planted in 2018 as the starting condition, compared to the observed live trees in the 2019 data. We compared this method to the more limited, but more certain permanent plot data and found better consistency. We tested using observed mortality from 2019 but that method underestimated mortality substantially.

Table 3: Seedling survival in each zone at the end of the growing season in 2019. Data from both transects and plots are combined. "All Seedlings" includes seedlings planted in 2018, plus natural regeneration and seedlings from previous planting projects. "Planted Seedlings" is the subset of seedlings that were planted in 2018. "Target TPA" is the goal regeneration density based on forest type.

Park	Zone	All Seedlings		Planted Seedlings Only (from 2018)		
		Live TPA	Target TPA[1]	TPA Live	TPA Dead	% Mortality
Carkeek Park	3A	168	200	61	185	75%
Arroyos Natural Area	Arroyos 47th Ave SW	27	125	4	167	98%
West Duwamish GS: Puget Park	Maduzia Gap	339	125	35	95	73%
West Duwamish GS: Puget Park	PPGS2	1415	200	96	71	43%
West Duwamish GS: Puget Park	PPGS3	336	200	50	89	64%
Duwamish Head Greenbelt	AW2	882	125	353	246	41%
East Duwamish GS: S Chicago St	Chicago	96	200	87	51	37%
East Duwamish GS: S Chicago St	Rose	34	200	23	92	80%
Seward Park	MF9	9	125	3	20	86%
Schmitz Preserve Park	Schmitz Blvd Slope	881	200	763	345	31%
Yesler Creek Headwaters	South Ravine Southend	442	200	408	0	0%
Discovery Park	Wolf Tree North	140	125	95	64	40%

[1]*Based on forest types: https://www.greenseattle.org/information-for/forest-steward-resources/restoration-resources/reference-ecosystems/*

Figure 1: Mortality by zone (transect and plot data combined). Values within the bars are the dead trees per acre calculated from original planting density in 2018 and field observations in late summer 2018 and 2019.

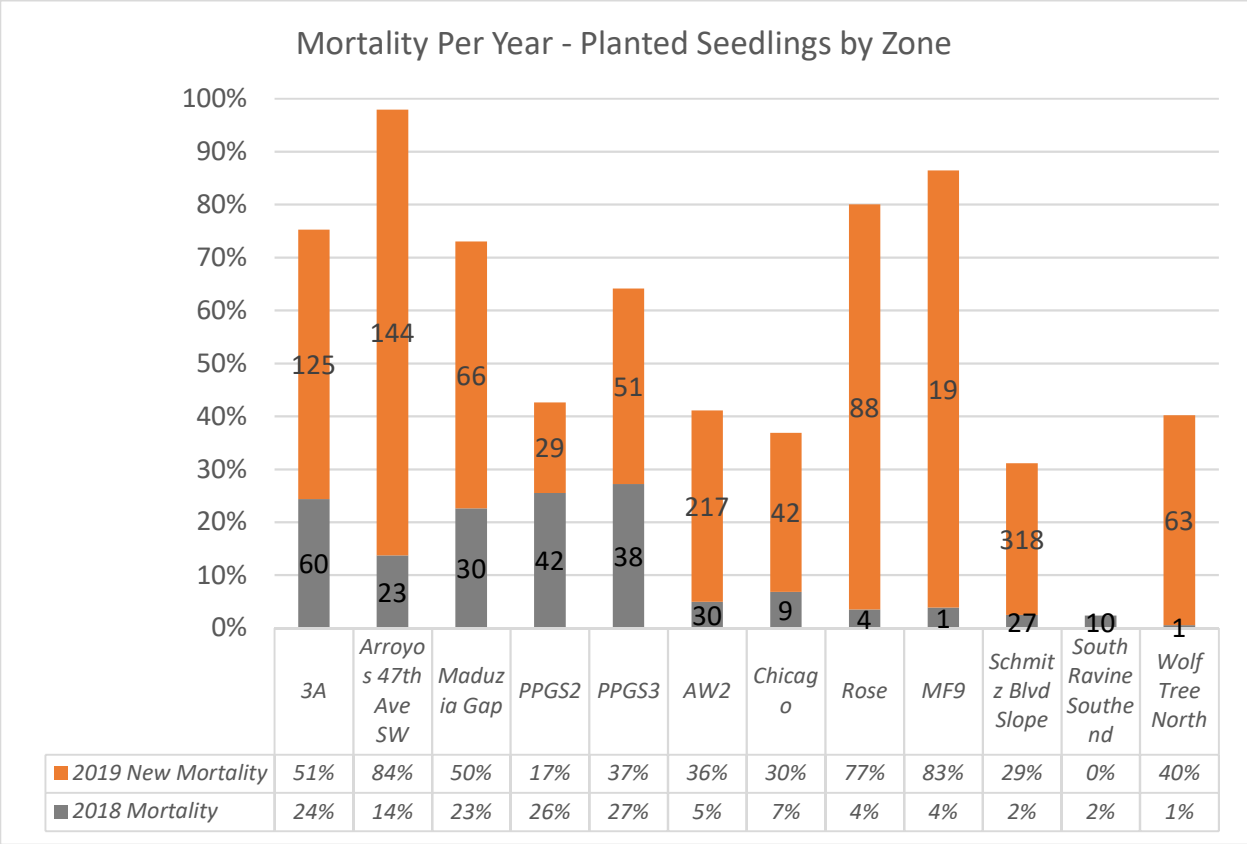


Table 4: Mortality by zone in 2018 and 2019 for all planted trees (transect and plot data combined).

Zone	2018 Total TPA	2018 Live TPA	2019 Live TPA	2018 Mortality	2019 New Mortality	2019 Total Mortality
3A	246	186	61	24%	51%	75%
Arroyos 47th Ave SW	171	147	4	14%	84%	98%
Maduzia Gap	131	101	35	23%	50%	73%
PPGS2	166	124	96	26%	17%	43%
PPGS3	139	101	50	27%	37%	64%
AW2	599	570	353	5%	36%	41%
Chicago	138	129	87	7%	30%	37%
Rose	115	111	23	4%	77%	80%
MF9	23	23	3	4%	83%	86%
Schmitz Blvd Slope	1108	1080	763	2%	29%	31%
South Ravine Southend	404	394	408	2%	0%	0%
Wolf Tree North	159	158	95	1%	40%	40%

Survival – Species

All species suffered substantial mortality. Broadleaf species including red alder, madrone, and Oregon ash had the highest mortality rates (>70%). Western redcedar, western hemlock, and Sitka spruce also had high mortality rates (between 56% and 63%), Douglas-fir and grand fir had somewhat better survival (49%, 36% mortality). Many factors affect seedling survival; analyses of key factors are in Section VI. Factors that Affect Survival.

Figure 2: Mortality by species (transect and plot data combined). Values within the bars are the number of dead trees that were calculated from original planting density in 2018 and field observations in late summer 2018 and 2019.

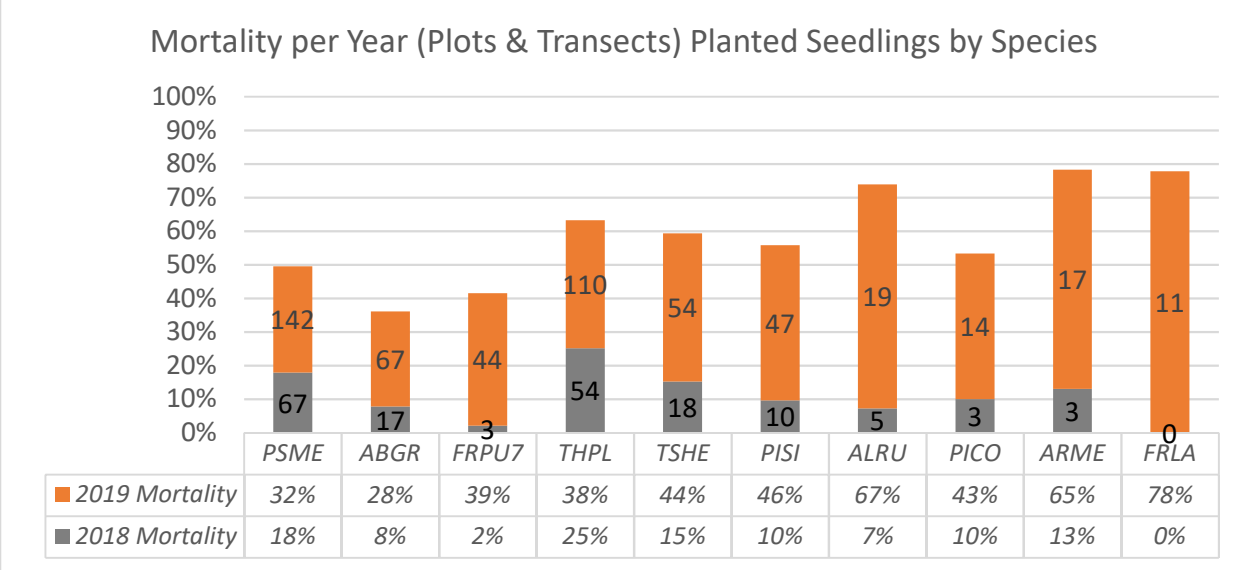


Table 5: Species mortality in 2018 and 2019 for all planted trees (transect and plot data combined).

Species	PSME	ABGR	FRPU7	THPL	TSHE	PISI	ALRU2	PICO	ARME	FRLA
2018 Total Planted	374	219	147	215	118	104	69	30	23	18
2018 Live Trees	307	202	144	161	100	94	64	27	20	18
2019 Live Trees	189	140	86	79	48	46	18	14	5	4
2018 Mortality	18%	8%	2%	25%	15%	10%	7%	10%	13%	0%
2019 New Mortality	32%	28%	39%	38%	44%	46%	67%	43%	65%	78%
2019 Total Mortality	49%	36%	41%	63%	59%	56%	74%	53%	78%	78%

VI. Factors That Affect Survival

Seedling survival depends on many interacting factors. This analysis focuses on three measurements of survival: 1) live or dead status, 2) vigor on a 0 through 3 scale where 0 = dead and 3 = healthy, and 3) seedling height, measured in feet. The factors that were measured that may influence survival, vigor, and/or height include:

- Canopy closure, which indicates light availability and competition with other trees
- Tall shrub cover (non-tree vegetation >6+ feet tall)
- Ground vegetation (non-tree vegetation <6 feet tall)
- Soil texture
- Seedling species
- Site preparation including mechanical and herbicide treatments of invasive plants
- Seedling maintenance including mulching, watering, and vegetation control

Seedling Vigor in 2018

Seedling vigor of live seedlings was significantly higher than in 2018 (2.7 in 2019 vs 2.3 in 2018 using the inverted vigor scale; Wilcoxon signed-rank test $p<0.000$). This indicates that in 2018, seedlings that were live but exhibited signs of stress did not survive to fall 2019.

Canopy Competition

Canopy competition, which was measured as percent canopy closure, indicates the light environment available for seedlings and the competition with other trees. Low canopy closure (an open canopy) allows more light to the ground with fewer trees to compete for resources, but can also stress shade-dependent species during hot, dry summer months. Generally, canopy closure changed little between 2018 and 2019. Sites with canopy closure over 50%, on average, suffered 74% mortality. Sites with canopy closure below 50% had, on average, 37% mortality. These results show up at statistically significant levels as well. At the zone level, data show a weak trend with more mortality (regardless of species) as canopy closure increased ($r^2 = 0.3885$, Figure 3), which we didn't find in 2018. A possible explanation for the emerging trend is that seedlings that were stressed in 2018, possibly due to canopy closure, died after field work in 2018 and those results are only now becoming visible.

Figure 3: Linear regression of percent seedling mortality and four competition factors (canopy closure, tall vegetation cover, short vegetation cover, and invasive plant cover).

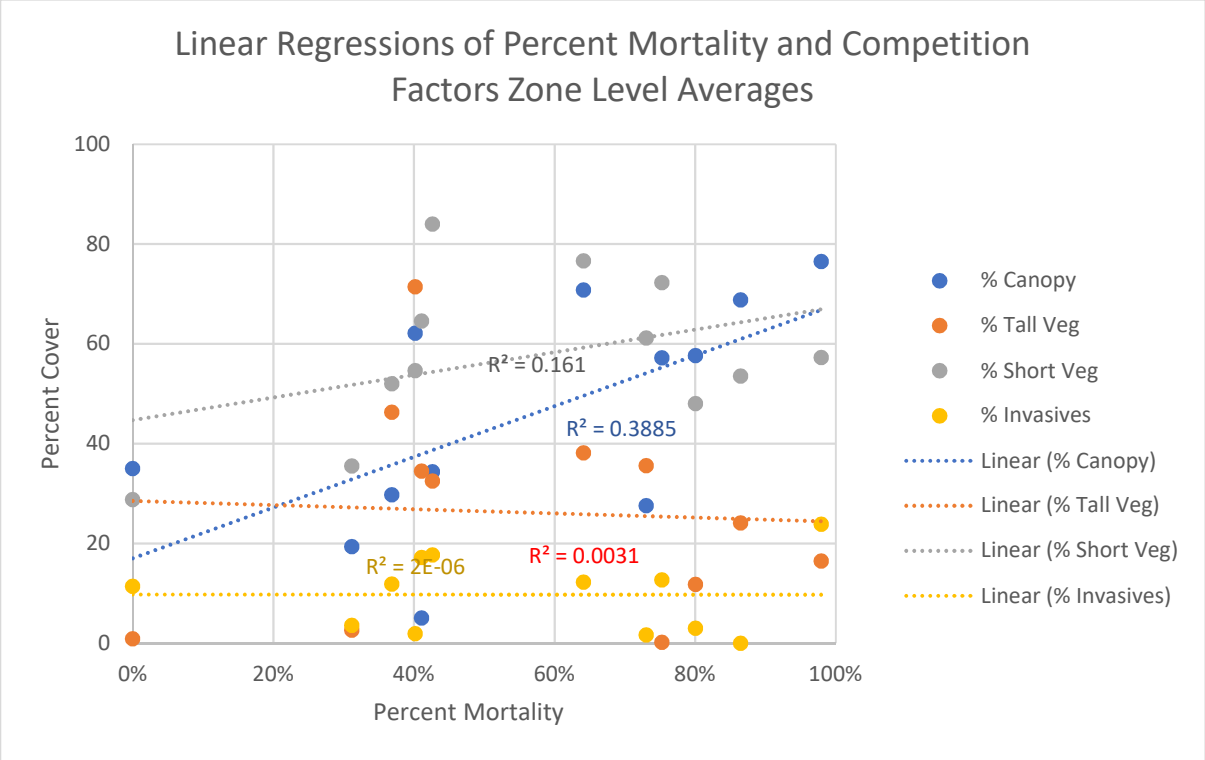


Table 6: Average seedling condition and competition factors at the zone scale.

Zone	% Mortality	Live Vigor[1]	Live Height	% Canopy	% Tall Veg	% Short Veg	% Invasives
3A	75%	2.9	1.9	57	0	72	13
Arroyos 47th Ave SW	98%	1.0	2.5	76	16	57	24
Maduzia Gap	73%	2.7	3.3	28	36	61	2
PPGS2	43%	2.7	2.8	34	33	84	18
PPGS3	64%	2.8	2.7	71	38	77	12
AW2	41%	2.9	4.4	5	34	65	17
Chicago	37%	2.9	3.1	30	46	52	12
Rose	80%	2.6	2.3	58	12	48	3
MF9	86%	1.3	1.0	69	24	54	0
Schmitz Blvd Slope	31%	2.6	3.7	19	3	36	4
South Ravine Southend	0%	2.7	2.9	35	1	29	11
Wolf Tree North	40%	2.7	3.6	62	71	55	2
Average	-	-	-	**40**	**29**	**61**	**11**

[1] Vigor of 3 = healthy, vigorous; 2 = visibly stressed but viable; 1 = alive but severely stressed or damaged

In 2018, we found that different seedling species responded in different ways to open canopies–sun-loving Douglas-fir and Sitka spruce did well in openings, but shade-tolerant species had higher mortality rates in openings. In 2019, there are no clear trend. In an analysis of variance (ANOVA) of live seedlings (Table 7, note this is different from the regressions above that looked at mortality rather than live seedling height) and four competition factors, grand fir, western redcedar, and Sitka spruce had a statistically significant height correlation to canopy openings (p=0.013, p=0.022, p=0.043, respectively), though there is a strong correlation (p<0.001) when looking at all seedlings combined.

Table 7: One-way analysis of variance (ANOVA) statistical test results for height of live planted seedlings compared with each of the four competition factors shown as column headings in the table. Each value represents a unique test result. Results that are significant at the 0.05 level are bolded and underlined. Results nearly significant at the 0.10 level are bolded and italicized.

Species	Sample (N)	Canopy Closure	Tall Veg	Short Veg	Invasives
PSME	189	0.906	***0.054***	0.471	0.915
ABGR	140	**0.013**	0.954	0.416	**0.038**
THPL	79	**0.022**	0.793	0.495	0.293
PISI	46	**0.043**	**0.005**	0.837	0.612
TSHE	48	0.441	0.739	0.282	0.196
FRPU7	86	0.236	0.471	0.970	0.353
PICO	14	0.517	0.508	0.856	1.000
All Species	675	**0.000**	0.133	0.541	**0.000**
All Conifers	516	0.107	**0.015**	0.739	***0.061***

Shrub and Ground Vegetation Competition

Forests in the Pacific Northwest tend to have robust shrub and forb vegetation. While dense native vegetation can be beneficial for wildlife habitat, it can devastate seedlings that are struggling to get enough light and water. Both short and tall shrub cover increased by about 19% between 2018 and 2019. In 2018, we found weak relationships between tall shrub cover and seedling mortality. That relationship disappeared in the 2019 data; tall vegetation, short vegetation, and invasive cover did not influence seedling mortality (Figure 3; $R^2 = 0.0031$, $R^2 = 0.161$, $R^2 < 0.000$ respectively). Anecdotally, field technicians observed that native vegetation such as trailing blackberry often overtopped and pushed over small seedlings, but short vegetation alone wasn't a statistically significant driver of mortality.

Tall vegetation limited the height of Sitka spruce seedlings (p=0.005), and affected conifer height generally when tested without discerning species (p=0.015). Meanwhile, short vegetation didn't limit height. When tested against all trees without consideration of species, invasive presence strongly correlates with shorter heights (P<0.001). Conifers together have a weak correlation with invasive species (p=0.061). That could be the result of the much larger sample size resulting in a statistically significant, though possibly not ecologically meaningful, effect on height. Invasive cover was relatively low, averaging 11% across all zones. Low invasive cover speaks to the success of invasive weed treatments before and after planting. To reconcile these results with the mortality regression in Figure 3, results in Table 7 show that once seedlings are established, canopy closure, tall vegetation, and invasive plant cover can limit height, while only high canopy closure correlates with killing off seedlings.

Soil Texture

Sandy and loamy soils correlated with higher survivorship, and silt and clay soils had lower survivorship among seedlings planted in 2018. Individual species showed similar trends as the overall mortality relationship with soils – generally, each species experienced higher mortality on clay and silt soils than sandy and loamy soils, except western hemlock, which faired worst on sand. Linear regression of depth of soil A horizon and mortality showed no relationship ($r^2 = 0.0204$). This analysis does not control for other environmental factors or management actions (i.e. mulching or watering), so conditions unrelated to soils could have an overriding effect on survivorship.

Results are counter-intuitive; we speculate that the limited sample size and the limited soil profile (only down to 18 inches, rather than several feet) provide an incomplete picture of the role of soil in seedling survival. We would expect well-drained sandy soils to become very dry in the summer and increase mortally, but the data show an opposite effect. Perhaps deeper soil pits would reveal compacted hard-pan layers or other features that would explain higher mortality in loamy and silty soils, which we would expect should have better survival.

Table 8: Soil texture at 18 inches deep and individual seedling survival within permanent plots.

Soil Texture	# of Plots in Sample	Live Seedlings	Dead Seedlings	Vigor (0-3)	Survival	Mortality
Silt	**3**	**14**	**40**	**2.9**	**26%**	**74%**
silt loam	*1*	*0*	*2*	*0.0*	*26%*	*74%*
silty clay	*1*	*11*	*11*	*3.0*	*37%*	*63%*
silty clay loam	*1*	*3*	*27*	*2.7*	*61%*	*39%*
Clay	**8**	**33**	**71**	**2.6**	**32%**	**68%**
clay	*5*	*31*	*28*	*2.5*	*53%*	*47%*
clay loam	*1*	*0*	*4*	*0.0*	*0%*	*100%*
clay sandy loam	*2*	*2*	*39*	*3*	*5%*	*95%*
Loam	**2**	**77**	**39**	**38**	**2.8**	**51%**
loamy sand	*2*	*77*	*39*	*38*	*2.8*	*51%*
Sand	**10**	**143**	**92**	**2.8**	**61%**	**39%**
sandy clay	*4*	*74*	*37*	*2.7*	*67%*	*33%*
sandy clay loam	*4*	*68*	*22*	*2.9*	*76%*	*24%*
sandy loam	*2*	*1*	*33*	*3.0*	*3%*	*97%*

Table 9: Dominant soil textures at each zone. This analysis cannot show causation, only correlation between seedling mortality and soil texture.

Park	Zone	% Mortality[1]	Dominant Soil Texture	Details
Carkeek Park	3A	72%	Clay	clay sandy loam, silty clay, sandy clay loam
Arroyos Natural Area	47th Ave SW	83%	Loam	Loamy sand, sandy loam
West Duwamish GS: Puget Park	Maduzia Gap	No Data	No Data	No Data
West Duwamish GS: Puget Park	PPGS2	20%	Clay	Clay, silty clay loam
West Duwamish GS: Puget Park	PPGS3	No Data	No Data	No Data
Duwamish Head Greenbelt	AW2	41%	Sand	Sandy clay, loamy sand
East Duwamish GS: S Chicago St	Chicago	65%	Sand	Sandy loam, sandy clay loam
East Duwamish GS: S Chicago St	Rose	85%	No Data	No Data
Seward Park	MF9	96%	Clay	Clay, clay loam, and silt loam
Schmitz Preserve Park	Schmitz Blvd Slope	No Data	No Data	No Data
Yesler Creek Headwaters	South Ravine Southend	2%	Sand	Sandy clay loam
Discovery Park	Wolf Tree North	40%	Sand	Sandy clay, sandy clay loam

[1]Mortality is for plot data only. Soils data only apply to plots.

Table 10: Seedling mortality for common species by dominant soil texture at 18 inches deep.

Species	Sample Size	Silt	Clay	Sand	Loam
PSME	142	100%	78%	35%	45%
ABGR	65	50%	55%	4%	25%
TSHE	22	29%	40%	60%	-
THPL	74	90%	91%	31%	54%
PISI	34	78%	33%	36%	-
ALRU	23	-	100%	64%	88%
FRPU7	61	-	62%	54%	73%
ARME	10	-	-	56%	0%

Site Prep, Planting, and Maintenance

Site preparation before planting, planting date and planting stock, and seedling maintenance after planting including shrub control and watering can all impact seedling survival (Table 11). Review of GSP's CEDAR database of restoration activities[3], communication with Seattle ecologists, and contractor project description reports provides data to assess the impacts of management actions on seedling survival.

Table 11: Management-related factors that may affect seedling survival. Data are from contractor's descriptions of work, and CEDAR database.

Park	Zone	Mortality (%)	Planting Dates	Planting Contractor	Planting Stock	Site Prep (2017-2018)	Mulch	Shrub Clearing (2019)	Watering 2018	Watering 2019
Carkeek Park	3A	75%	2/26/2018-3/9/2018	EarthCorps	bare root	none	no	ez-ject woody invasives, hand grub invasives, foliar treatment of ivy, cut and treat blackberry	no	no
Arroyos Natural Area	Arroyos 47th Ave SW	98%	No Data	No Data	bare root, pots	herbicide treatment of knotweed	no	knotweed herbicide	no	no
West Duwamish Green Space: Puget Park	Maduzia Gap	73%	1/31/2018, 3/15/2018	Garden Cycles	bare root, pots	none	no	Weeding, brushing-conifer release	no	no
West Duwamish Green Space: Puget Park	PPGS2	43%	10/13/2017-3/2/2018	Garden Cycles	bare root, pots	brushing cone, scarify	yes	foliar herbicide – blackberry, ivy; brushing-conifer release	no	no
West Duwamish Green Space: Puget Park	PPGS3	64%	10/13/2017-3/2/2018	Garden Cycles	bare root, pots	brushing cone, scarify	yes	foliar herbicide – blackberry, ivy; brushing-conifer release	no	no
Duwamish Head Greenbelt	AW2	41%	10/30/2017-3/30/2018	Garden Cycles	bare root, pots, stakes	brushing, small tree felling	Yes, cedar grove product	none	yes	yes

[3] Green Seattle Partnership Central Data Repository (CEDAR). https://www.greenseattle.org/information-for/forest-steward-resources/cedar-how-to/. Accessed data from 1/1/2018 through 10/20/2019 on October 22, 2019.

Park	Zone	Mortality (%)	Planting Dates	Planting Contractor	Planting Stock	Site Prep (2017-2018)	Mulch	Shrub Clearing (2019)	Watering 2018	Watering 2019
East Duwamish Green Space	Chicago	37%	11/14/2017-3/12/2018	Applied Ecology	bare root, pots	brushing, blackberry removal	yes	none	no	no
East Duwamish Green Space	Rose	80%	11/13/2017-3/7/2018	Applied Ecology	bare root, pots	brushing, blackberry removal	yes	none	no	no
Seward Park	MF9	86%	3/15/2018-3/30/2018	EarthCorps	bare root, pots	none	no	none	no	no
Schmitz Preserve Park	Schmitz Blvd Slope	31%	3/10/2018-3/22/2018	Monarch Landscapes	pots	brushing, blackberry removal	Yes, cedar grove product	herbicide, brushing and mechanical blackberry control	yes	no
Yesler Creek Headwaters	South Ravine Southend	0%	No Data	No Data	pots	brushing, blackberry removal	Yes, mixed with soil when back-filling	brushing and mechanical blackberry control	yes	yes
Discovery Park	Wolf Tree North	40%	2/20/2018-3/9 2018	Monarch Landscapes	pots	none	no	none	no	no

Site preparation: Analysis of the site prep and seedling maintenance data indicate some trends. The strongest result is that watering correlated with much lower mortality. Sites that were watered had on average 26% mortality, while un-watered sites had 65% mortality. Watered sites also tended to have mulching and brushing, so it is hard to discern the combined benefits of these seedling maintenance activities versus watering alone. Mulching in 2018 seems to have a slight benefit, with mulched seedlings having about 11% better survival than un-mulched sites. Brushing that took place in 2019 has a small sample size, and it's unclear if seedlings would have responded in a measurable way in time for the 2019 data collection – seedlings typically don't grow much once summer sets in. Research and professional experience indicate the reducing adjacent vegetation competition (e.g., cutting cones of light) benefit seedling survival, but this data set isn't able to test that correlation yet.

Seedling stock: Seedling stock, nursery sourcing, and inoculation may play a role in seedling survival but was beyond the scope of this analysis. SPR would need to track individual seedlings and document their stock, source, and pre-planting treatment in order to determine survival outcomes. Sites that had exclusively potted seedling stock (versus a mix of potted and bare root for most sites) had among the highest rates of survival of all zones; however, two of these sites were watered and it is unclear if potted stock alone was a significant contributing factor to the sites' successes.

Mechanical damage: Field workers noted that where mechanical brushing took place, live seedlings were sometimes cut in half. This was noted most frequently at PPGS2. An accidentally cut tree every once-in-a-while is unavoidable and the overall impact of this is probably small. However, in sites where seedling survival is low, every seedling becomes important.

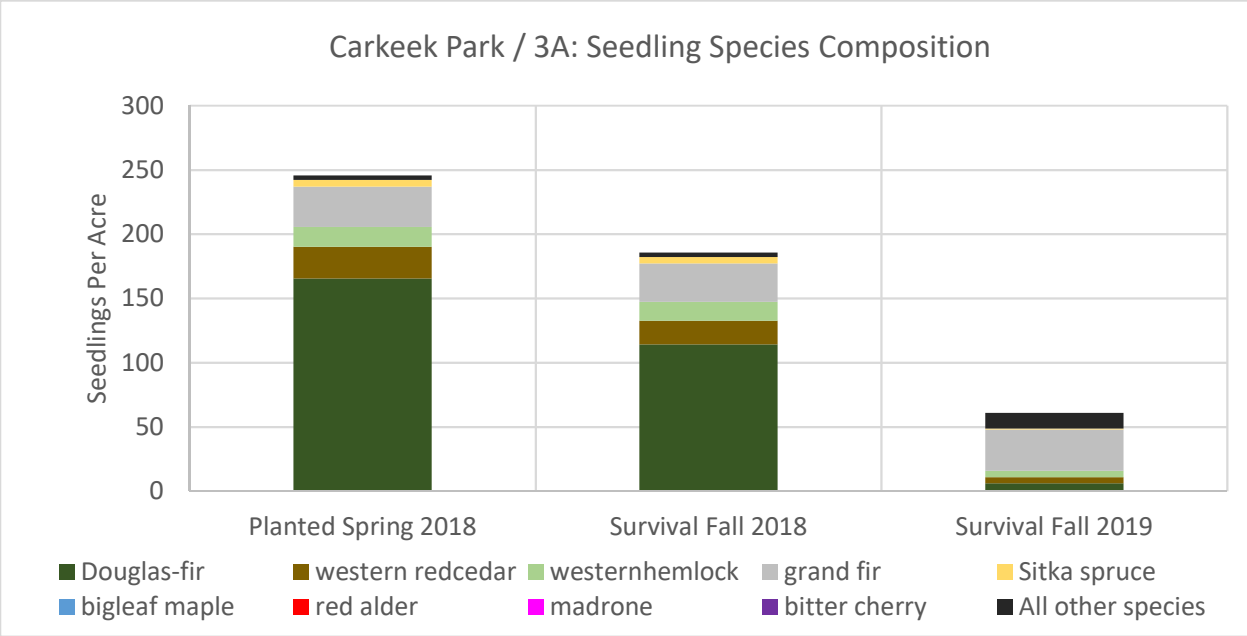
Caging: Wire or plastic mesh cages were installed on all conifers at Carkeek 3A, according to contractor records. In transect data, 65% of live conifers had cages with notes of crushing or being overtaken with field bindweed (*Convolvulus arvensis*). We don't have good data for dead seedlings that may have been crushed by fallen cages – cages can get pulled off by people or animals, and these discarded cages are difficult to differentiate from cages around dead and lost seedlings. Since the planting wasn't intended for study, no controls were set up to compare mortality of caged versus un-caged seedlings. Further, we can't differentiate the impact of cages being overtaken by bindweed versus damaging impacts of cages themselves, or if cages influence bindweed growth.

VII. Zone Narratives and Species Composition Densities

The following series of figures show all data (combined transect and plot data), breaking out species composition of all seedlings at four points in the planting project progression. First, the as-planted condition from immediately after planting took place, calculated by assuming all trees observed in 2018 were alive at the time of planting. Second, the observed seedling conditions in late summer 2018. Third, the observed conditions in late summer 2019. These graphs include only seedlings planted in 2018.

The nature of the data collection methods results in a few zones with species that had more seedlings in 2019 than in 2018. Year-to-year variability is due to variation in data collection inherent in the transect sampling method.

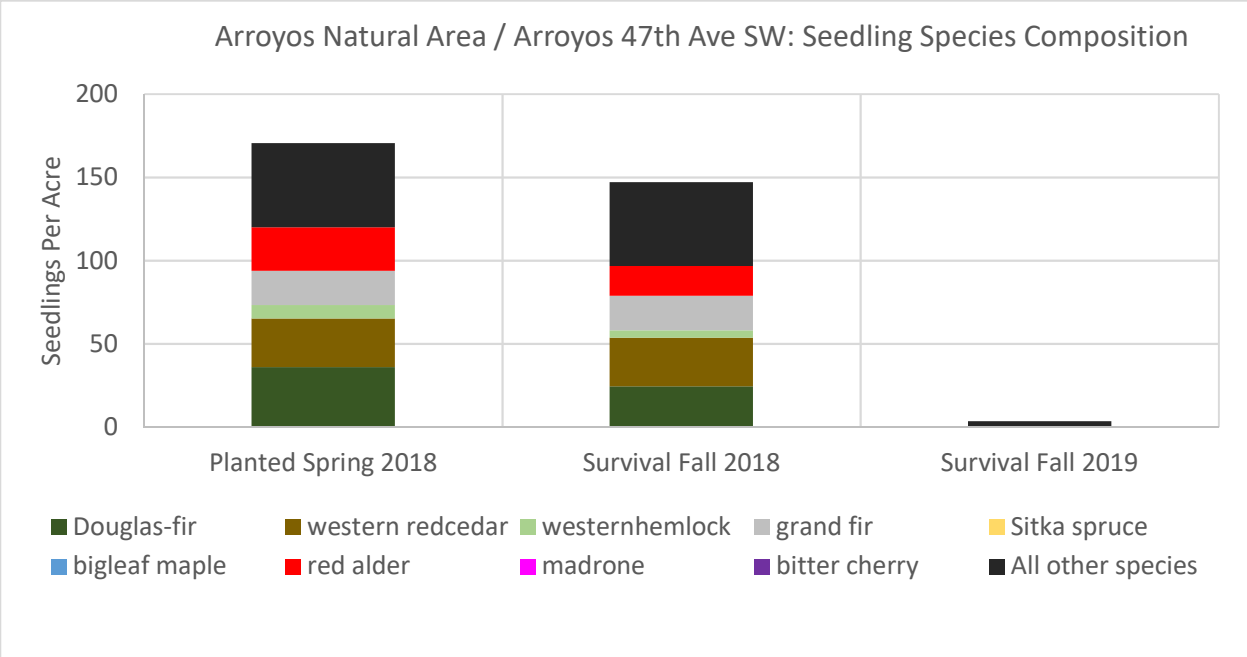
Carkeek Park / 3A



Carkeek Park / 3A: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	165	114	*51*	6	*108*	**96%**
THPL	25	18	*6*	5	*14*	**81%**
TSHE	16	15	*1*	5	*10*	**68%**
ABGR	31	30	*2*	32	*0*	**0%**
PISI	5	5	*0*	1	*4*	**84%**
ACMA	0	0	*0*	0	*0*	**0%**
All Other	3	3	*0*	12	*0*	**0%**
Totals	**246**	**186**	***60***	**61**	***125***	**75%**

Carkeek Zone 3A suffered high losses in the last year. This site is in a deep north-south ravine which inhibits light. Unique to this site, wire cages and photodegradable tubes were installed around seedlings at the time of planting. Cages can be helpful to mitigate mountain beaver browse, which are common here, but may cause more harm than good in this case. Field workers noted the cages were often leaning over or were entangled with invasive bindweed. Seedling cages require annual maintenance to limit mechanical damage. Soil pits installed at the permanent plots showed clay soils, which correlate with high mortality. This site also has somewhat high canopy closure (57%), limiting available light to the seedlings, and short vegetation is dense at 72% cover. The sun-dependent Douglas-fir suffered near total mortality. Shade tolerant western rededcar and western hemlock also did poorly, suggesting that other factors in addition to canopy closure played a role. Grand fir did remarkably well, with no losses (year-to-year differences are due to variation inherent in the sample design). This project did not undergo site prep, had no mulch, and was not watered. Invasive plants were removed in summer 2019.

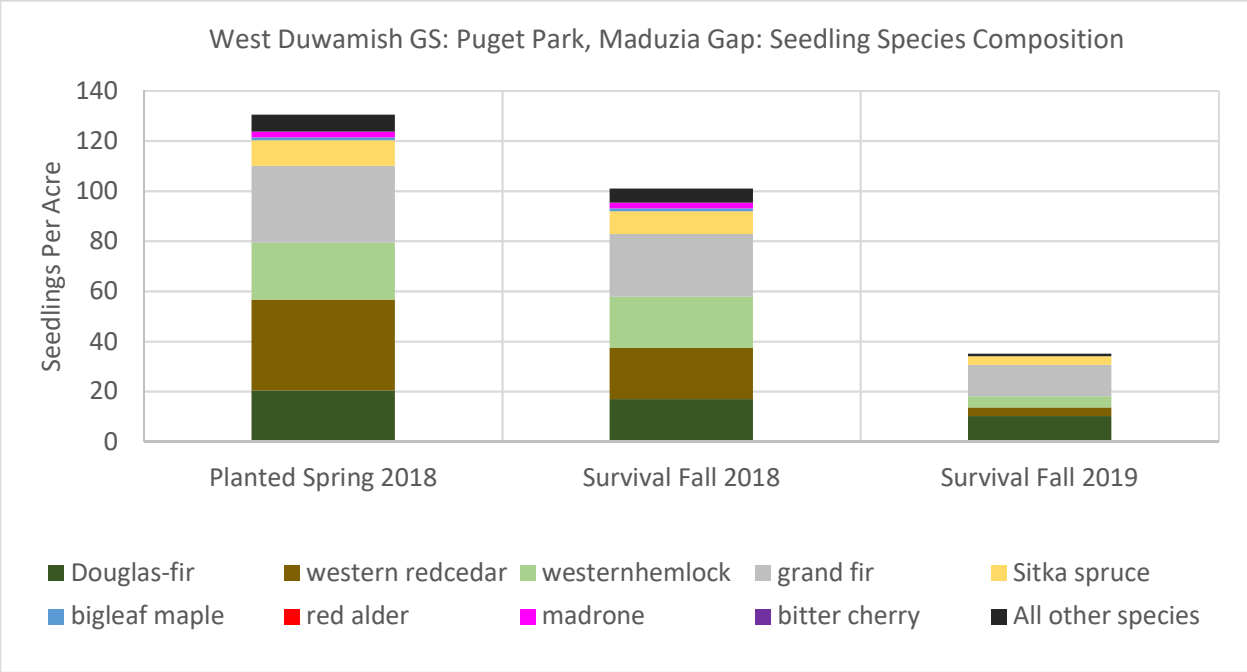
Arroyos Natural Area / Arroyos 47th Ave SW



Arroyos Natural Area / Arroyos 47th Ave SW: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	36	24	*12*	0	*24*	**100%**
THPL	29	29	*0*	0	*29*	**100%**
TSHE	8	5	*4*	0	*5*	**100%**
ABGR	21	21	*0*	0	*21*	**100%**
PISI	0	0	*0*	0	*0*	**NA**
ACMA	0	0	*0*	0	*0*	**NA**
ALRU	26	18	*8*	0	*18*	**100%**
ARME	0	0	*0*	0	*0*	**NA**
All Other	51	51	*0*	4	*47*	**93%**
Totals	**171**	**147**	***23***	**4**	***144***	**98%**

Arroyos Natural Area zone Arroyos 47th Ave SW suffered severe losses in the last year. Soil pits installed at the permanent plots showed loam and sandy soils, which elsewhere in the city correlated with only moderate mortality but was not the case here. Field worker notes indicated below the 18" soil pit was a hardpan, which limits moisture availability during drought. The site is very exposed, steep, and west-facing on Puget Sound. This site has high canopy closure (76%), limiting available light to the seedlings. Short vegetation coverage is moderate at 57%. The diverse seedling species composition uniformly suffered losses, both sun-dependent and shade-tolerant species. This project underwent knotweed herbicide in advance of planting, and again in 2019. The seedlings were not mulched and were not watered due difficult access. The cause of such complete loss is hard to explain from the data, but the exposed conditions may be a driving factor.

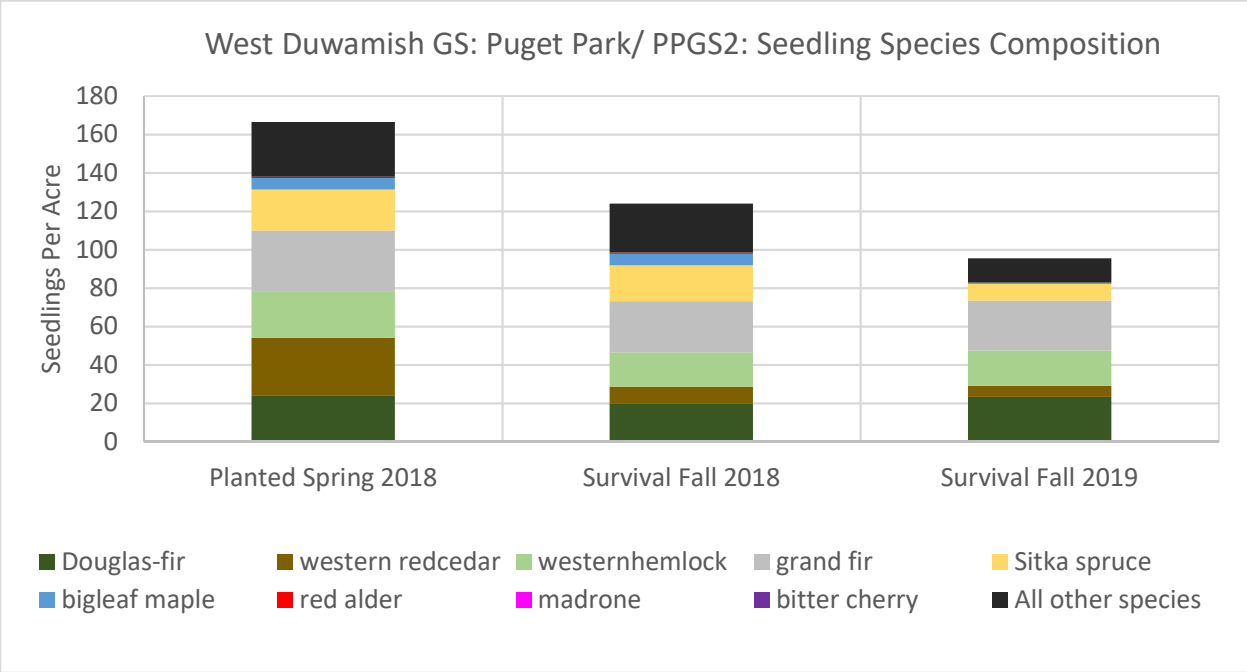
West Duwamish GS: Puget Park / Maduzia Gap



West Duwamish GS: Puget Park / Maduzia Gap: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	20	17	*3*	10	*7*	**50%**
THPL	36	20	*16*	3	*17*	**91%**
TSHE	23	20	*2*	5	*16*	**80%**
ABGR	31	25	*6*	12	*12*	**59%**
PISI	10	9	*1*	3	*6*	**67%**
ACMA	1	1	*0*	0	*1*	**100%**
ALRU	0	0	*0*	0	*0*	**NA**
ARME	2	2	*0*	0	*2*	**100%**
All Other	7	6	*1*	1	*5*	**83%**
Totals	**131**	**101**	***30***	**35**	***66***	**73%**

Maduzia Gap suffered moderate to high losses in the last year. Shade tolerant species generally had higher mortality than sun-dependent species. Maduzia Gap underwent a thinning and gap treatment before the 2018 planting, where broadleaf trees were cut with the goal of increasing light to the ground to help transition to a mixed conifer composition. Seedlings from a previous planting project were growing well, often taller than adjacent shrubs. As expected, this site has low canopy closure (28%). Short vegetation coverage is moderate at 61%, though where it occurred, trailing blackberry formed a thick mat that can choke out seedlings. The site had no site prep, no mulch, but was weeded and brushed (conifer release) in 2019. This site has no soil data.

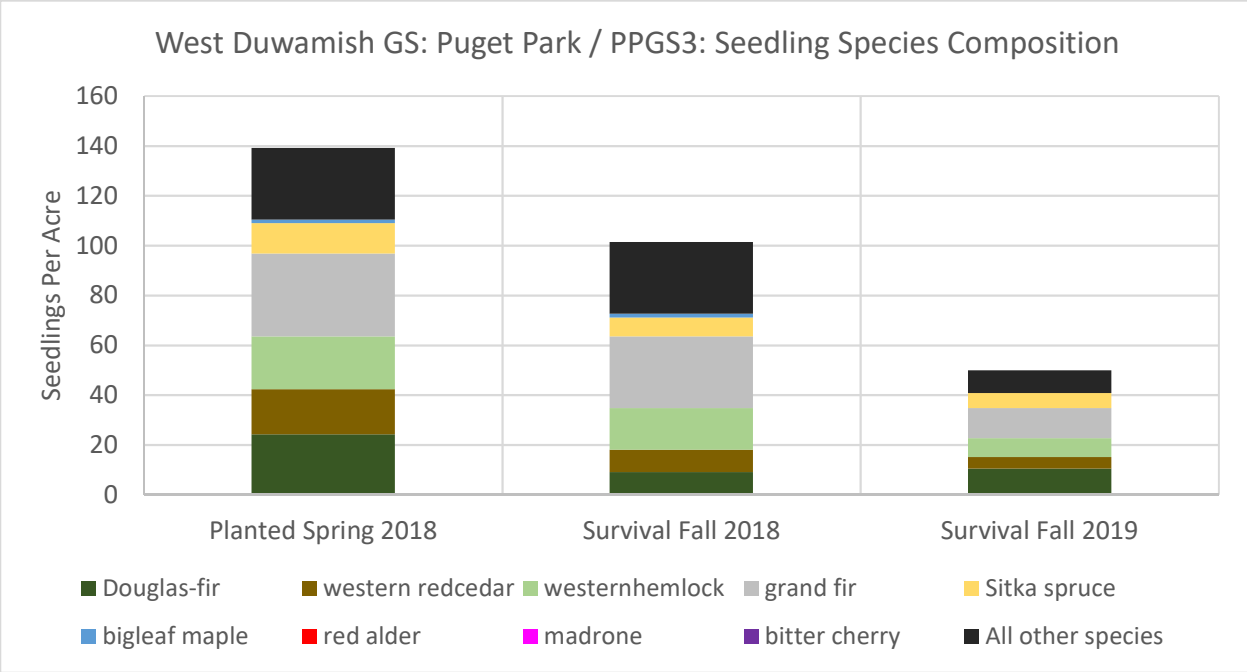
West Duwamish GS: Puget Park / PPGS2



West Duwamish GS: Puget Park / PPGS2: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	24	20	*5*	23	*0*	**4%**
THPL	30	9	*21*	6	*3*	**80%**
TSHE	24	18	*6*	18	*0*	**23%**
ABGR	32	27	*5*	26	*1*	**19%**
PISI	21	19	*3*	9	*10*	**59%**
ACMA	6	6	*0*	1	*5*	**88%**
ALRU	1	1	*0*	0	*1*	**100%**
ARME	0	0	*0*	0	*0*	**NA**
All Other	29	25	*3*	13	*13*	**56%**
Totals	**166**	**124**	***42***	**96**	***29***	**43%**

West Duwamish Greenspace zone PPGS2 fared better than most zones, retaining most of the Douglas-fir but losing much of the western redcedar. PPGS2 underwent a thinning and gap treatment before the 2018 planting, where broadleaf trees were cut with the goal of increasing light to the ground to help transition to a mixed conifer composition. Soil pits installed at the permanent plots showed clay-dominated soils, correlating with moderate mortality. This site has an open canopy closure (34%), letting light into the forest but probably causing the dense coverage of short vegetation (84%). This site received site preparation in the form of brushing cones and scarification. In 2019, the site had herbicide treatments to control Himalayan blackberry and English ivy, and brushing to release conifers. The seedlings were mulched, but not watered.

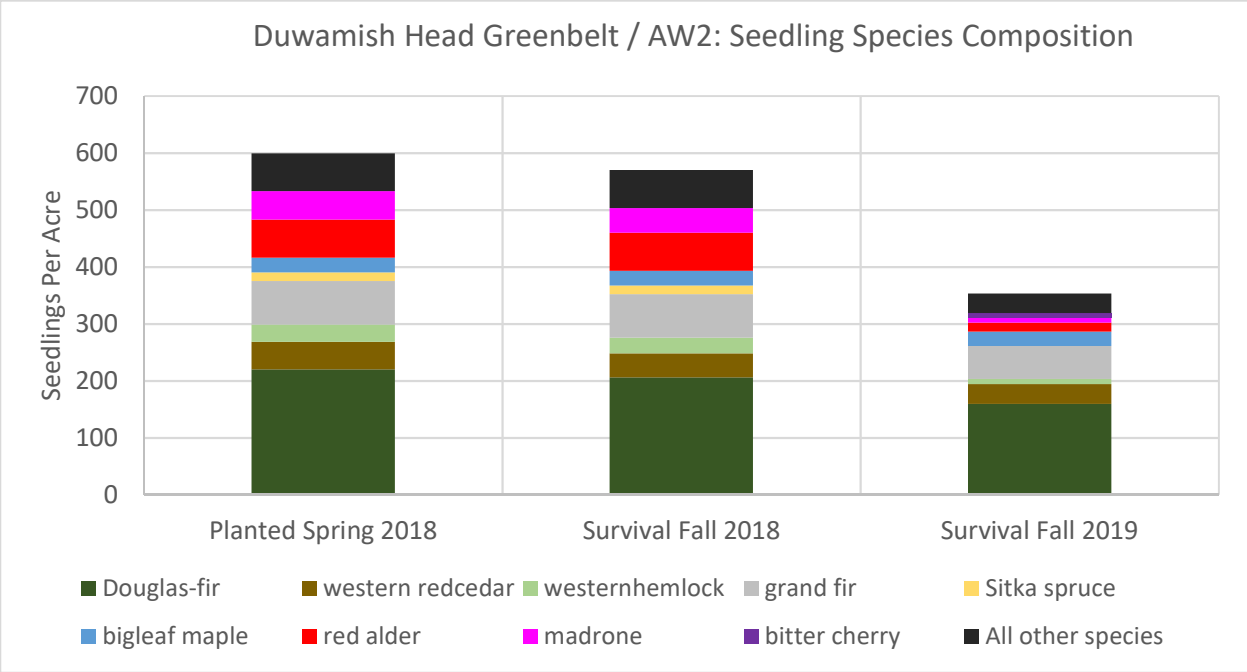
West Duwamish GS: Puget Park / PPGS3



West Duwamish GS: Puget Park / PPGS3: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	24	9	*15*	11	*0*	**56%**
THPL	18	9	*9*	5	*5*	**75%**
TSHE	21	17	*5*	8	*9*	**64%**
ABGR	33	29	*5*	12	*17*	**64%**
PISI / SS	12	8	*5*	6	*2*	**50%**
ACMA	2	2	*0*	0	*2*	**100%**
ALRU	0	0	*0*	0	*0*	**NA**
ARME	0	0	*0*	0	*0*	**NA**
All Other	29	29	*0*	9	*20*	**68%**
Totals	**139**	**101**	***38***	**50**	***51***	**64%**

West Duwamish Greenspace zone PPGS3 experienced moderate to high mortality, with shade tolerant western redcedar, grand fir, and western hemlock suffering slightly higher mortality than sun-dependent Douglas-fir and Sitka spruce. PPGS3 underwent a thinning and gap treatment before the 2018 planting, where broadleaf trees were cut with the goal of increasing light to the ground to help transition to a mixed conifer composition. No soil data is available for this site. This site is very similar to PPGS2, but has a more closed canopy (71%), and also has a dense coverage of short vegetation (77%) with denser tall vegetation than most sites (38%). This site received site preparation in the form of brushing cone and scarification. The seedlings were mulched, but not watered. In 2019, the site had herbicide and manual treatments to control Himalayan blackberry and English ivy.

Duwamish Head Greenbelt / AW2

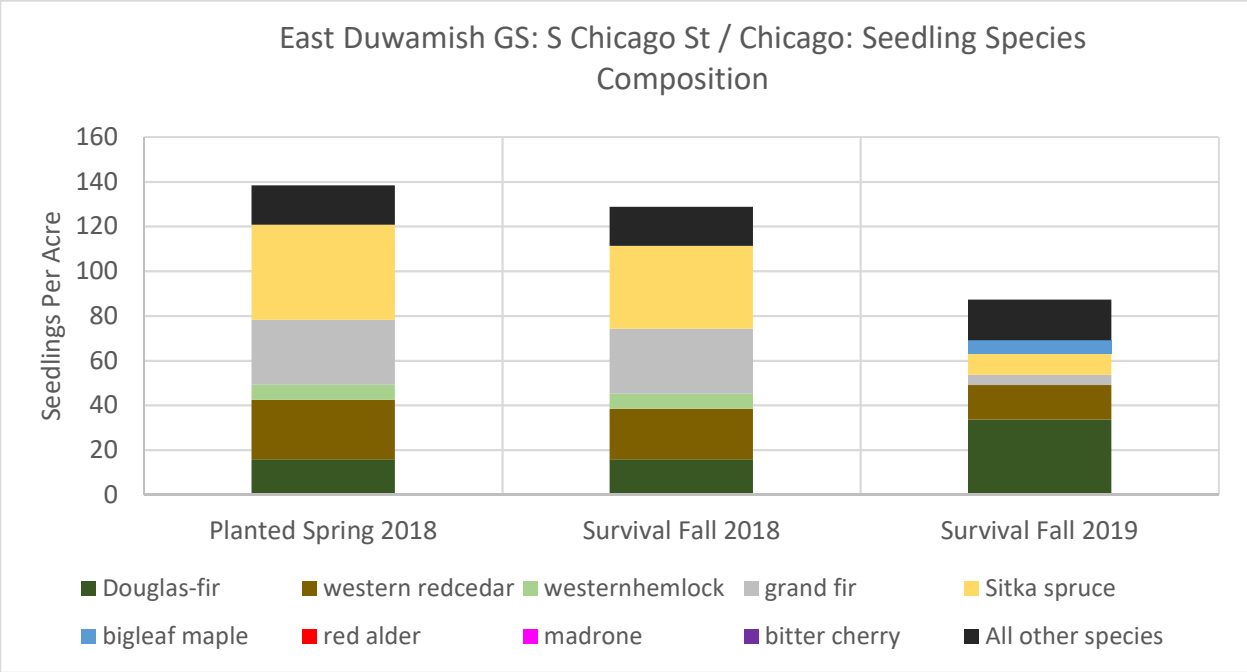


Duwamish Head Greenbelt/ AW2: Live Seedling Species Composition (trees/acre)

Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	220	206	*14*	160	*47*	**27%**
THPL	48	42	*6*	35	*8*	**29%**
TSHE	30	27	*3*	9	*18*	**70%**
ABGR	76	76	*0*	58	*18*	**24%**
PISI	15	15	*0*	0	*15*	**100%**
ACMA	26	26	*0*	25	*1*	**4%**
ALRU	67	67	*0*	16	*51*	**76%**
ARME	50	44	*6*	8	*35*	**83%**
All Other	66	66	*0*	43	*24*	**36%**
Totals	**599**	**570**	***30***	**353**	***217***	**41%**

Duwamish Head Greenbelt zone AW2 retained a majority of its seedlings, with western hemlock, Sitka spruce, and red alder doing worse than others. Madrone was planted at this site but experienced high mortality, though the madrone that survived have high vigor and are tall (3.8 feet, on average). Soil pits installed at the permanent plots showed sandy soils, correlating with lower mortality. This site has a wide-open canopy (5% closure), letting full sun to the ground. Tall and short vegetation are both somewhat dense at 34% and 65%, respectively. Average seedling height is tallest here at 4.4 feet and vigor is highest at 2.9. This site has been extensively weeded and watered since the time of installation as part of the Duwamish Head Mitigation. The seedlings were “deeply mulched” with wood chips according to the contractor. The site also received compost blow-in of Cedar Grove product prior to installation. Notably, the site was watered in both 2018 and 2019. No follow-up vegetation control took place after planting.

East Duwamish GS: S Chicago St / Chicago

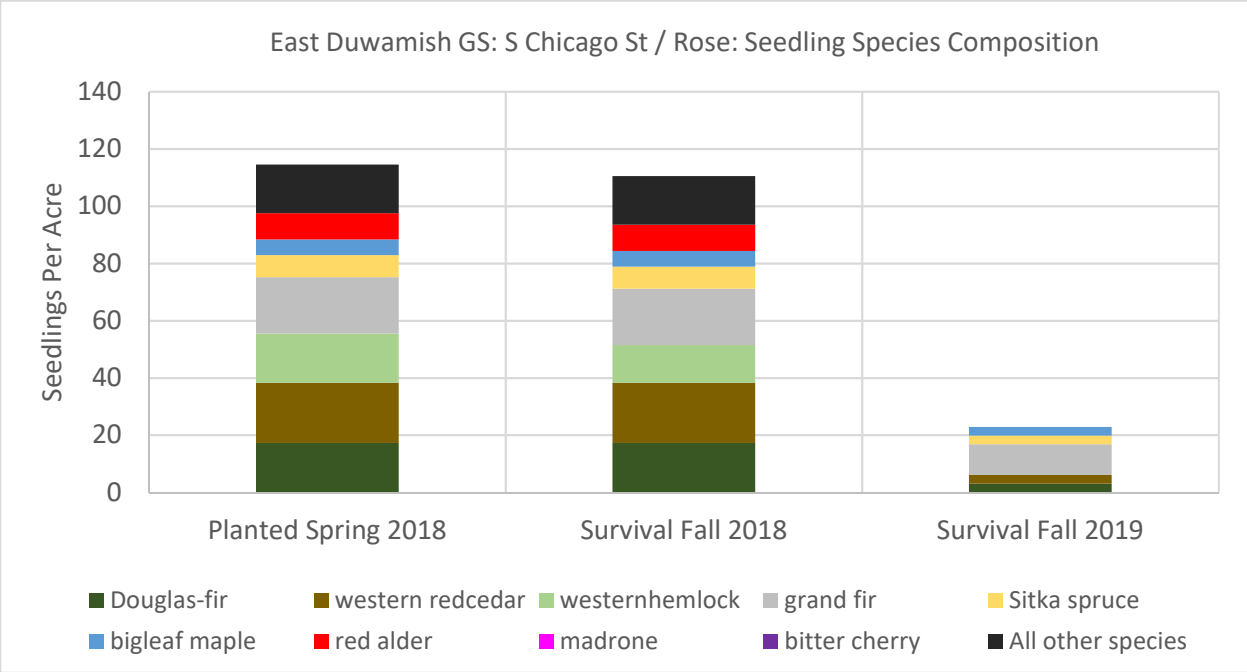


East Duwamish GS: S Chicago St / Chicago: Live Seedling Species Composition (trees/acre)

Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME F	16	16	*0*	34	*0*	**0%**
THPL	27	23	*4*	15	*7*	**42%**
TSHE	7	7	*0*	0	*7*	**100%**
ABGR	29	29	*0*	5	*24*	**84%**
PISI	43	37	*5*	9	*28*	**78%**
ACMA	0	0	*0*	6	*0*	**0%**
ALRU	0	0	*0*	0	*0*	**0%**
ARME	0	0	*0*	0	*0*	**0%**
All Other	18	18	*0*	18	*0*	**0%**
Totals	**138**	**129**	***9***	**87**	***42***	**37%**

East Duwamish Greenspace zone Chicago retained a majority of its seedlings, though western hemlock was wiped out, and grand fir and Sitka spruce are doing poorly. Douglas-fir is doing very well. There is good moisture on the south end of the site. Soil pits installed at the permanent plots showed sandy soils, correlating with lower mortality. This site has an open canopy (30% closure). Tall vegetation is relatively dense here, and short vegetation is moderate at 46% and 52%, respectively. The site has high vigor among its surviving seedlings at 2.9. This site received several years of invasive removal prior to plant installation and weeding in 2018. This site received brushing as site prep for planting, and seedlings were mulched. No follow-up vegetation control took place after plantings. Variability in the sampling between 2018 and 2019 resulted in more Douglas-fir and other species observed in 2019 than in 2018; no additional planting took place.

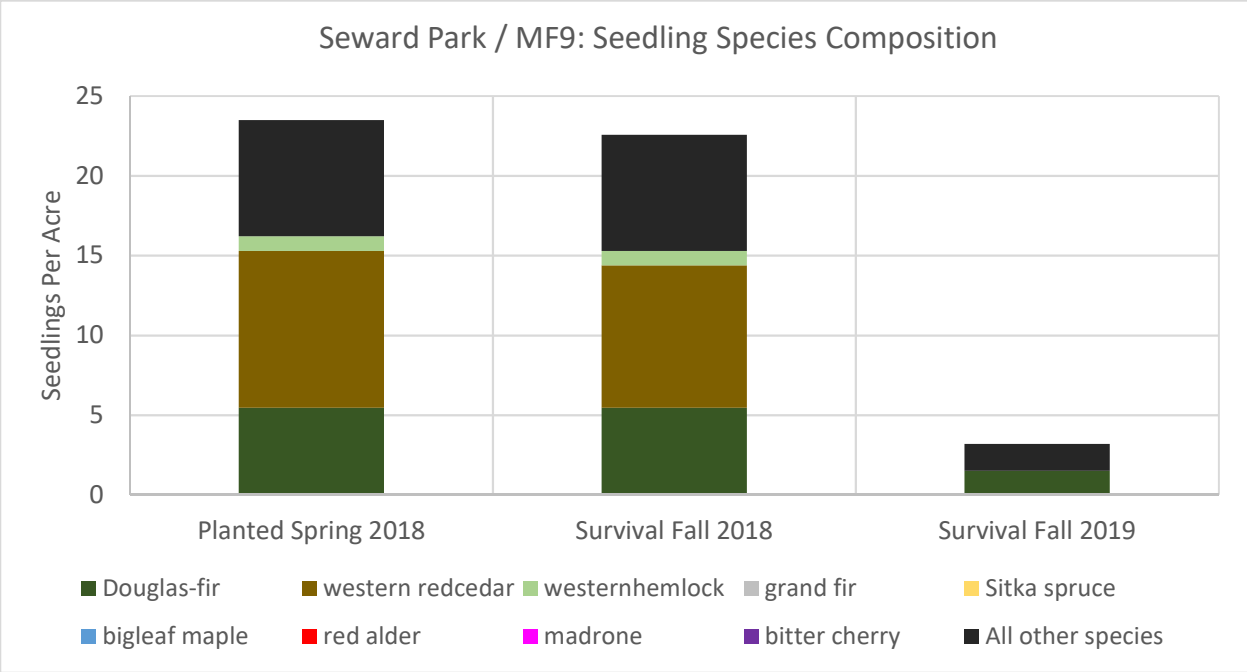
East Duwamish GS: S Chicago St / Rose



East Duwamish GS: S Chicago St / Rose: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	17	17	*0*	3	*14*	**82%**
THPL	21	21	*0*	3	*18*	**86%**
TSHE	17	13	*4*	0	*13*	**100%**
ABGR	20	20	*0*	11	*9*	**45%**
PISI	8	8	*0*	3	*5*	**61%**
ACMA	5	5	*0*	3	*2*	**44%**
ALRU	9	9	*0*	0	*9*	**100%**
ARME	0	0	*0*	0	*0*	**0%**
All Other	17	17	*0*	0	*17*	**100%**
Totals	**115**	**111**	***4***	**23**	***88***	**80%**

East Duwamish Greenspace zone Rose suffered high mortality between 2018 and 2019. Sitka spruce and grand fir managed to avoid the highest rates of mortality; western hemlock, western redcedar, and Douglas-fir lost most individuals. No soil data were collected at this site. This site has a somewhat closed canopy of bigleaf maple (58%). Tall and short vegetation are moderate (12% and 48%, respectively). Seedlings tend to be short here at 2.3 feet tall on average. Field worker notes indicate the seedlings appeared to have been out-competed by vegetation, including tall grass, fireweed, and widespread natural first-year bigleaf maple seedlings. This site received several years of invasive removal prior to plant installation and weeding in 2018. This site received brushing as site prep for planting, and seedlings were mulched. No work took place in 2019.

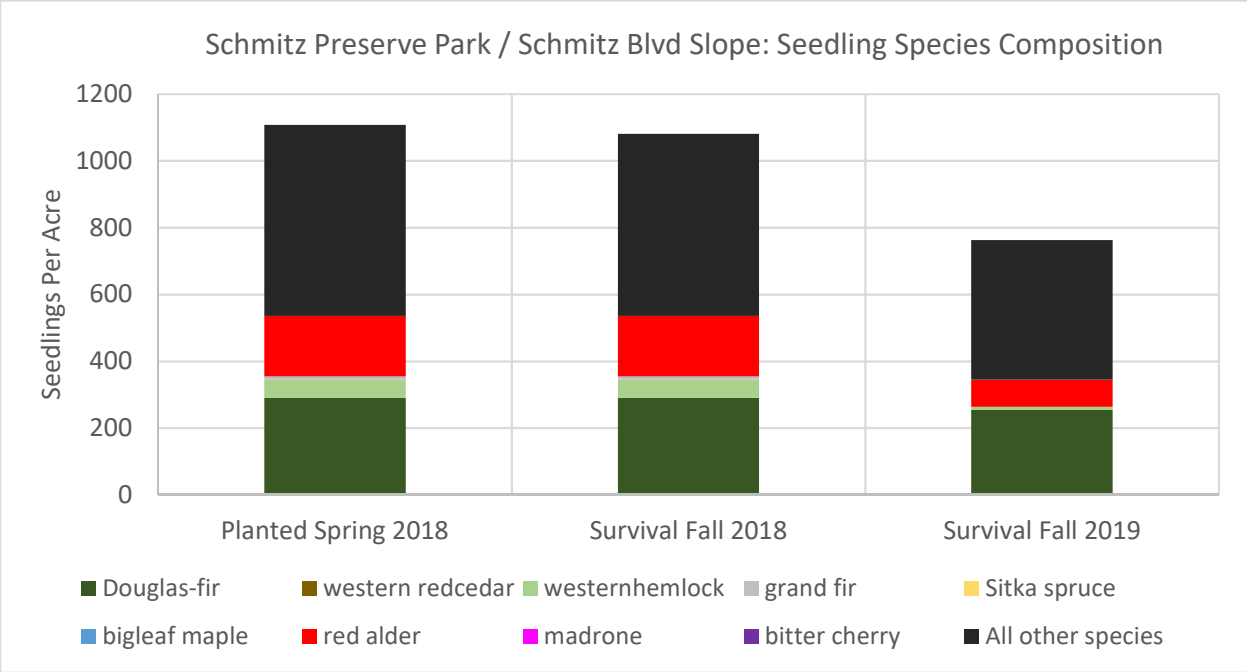
Seward Park / MF9



Seward Park / MF9: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	5	5	*0*	2	*4*	**72%**
THPL	10	9	*1*	0	*9*	**100%**
TSHE	1	1	*0*	0	*1*	**100%**
ABGR	0	0	*0*	0	*0*	**0%**
PISI	0	0	*0*	0	*0*	**0%**
ACMA	0	0	*0*	0	*0*	**0%**
ALRU	0	0	*0*	0	*0*	**0%**
ARME	0	0	*0*	0	*0*	**0%**
All Other	7	7	*0*	2	*6*	**77%**
Totals	**23**	**23**	***1***	**3**	***19***	**86%**

Seward Park zone MF9 was sparsely planted, and lost most of its seedlings across all species. Soil pits installed at the permanent plots showed clay soils, correlating with high mortality. Field worker notes say this site is rocky with shallow soils. This site has a dense canopy (69% closure) of large old trees. Tall and short vegetation are moderate at 24% and 56%, respectively. The site has the shortest trees of any site (average 1.0 feet) and has low vigor of 1.3. This site received no site prep in 2018 but had low weed cover to begin with since invasive removal was completed in years prior. No follow-up treatments took place.

Schmitz Preserve Park / Schmitz Blvd Slope

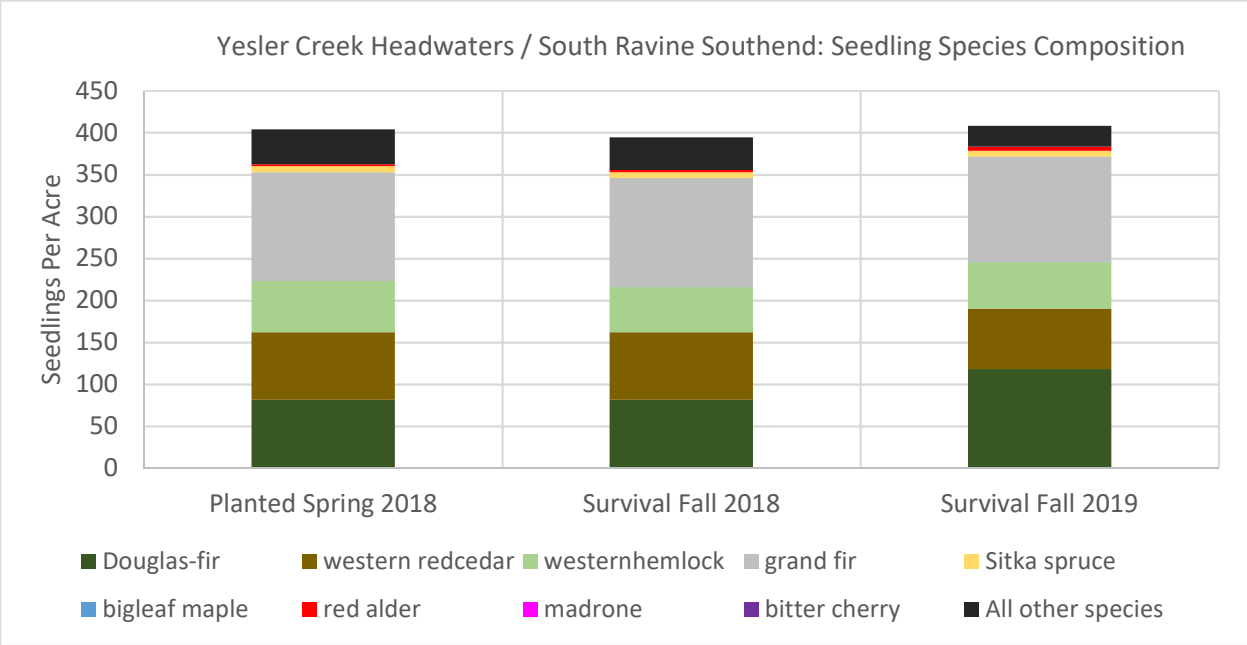


Schmitz Preserve Park / Schmitz Blvd Slope: Live Seedling Species Composition (trees/acre)

Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	291	291	*0*	254	*36*	**13%**
THPL	0	0	*0*	0	*0*	**NA**
TSHE	54	54	*0*	9	*45*	**83%**
ABGR	9	9	*0*	0	*9*	**100%**
PISI	0	0	*0*	0	*0*	**NA**
ACMA	0	0	*0*	0	*0*	**NA**
ALRU	182	182	*0*	82	*100*	**55%**
ARME	0	0	*0*	0	*0*	**NA**
All Other	572	545	*27*	418	*127*	**27%**
Totals	**1108**	**1080**	***27***	**763**	***318***	**31%**

Schmitz Preserve zone Schmitz Blvd Slope has the second-highest seedling survival of all the sites. Total planted seedlings per acres soars to 763, which is an extremely crowded condition. Red alder and cascara make up 65% of that density. Douglas-fir was extensively planted in this open site, and it did well despite the competition with broadleaf seedlings. Western hemlock and grand fir did poorly. No soil pits were installed. This site has an open canopy (19% closure). Tall and short vegetation are sparse, leaving plenty of room for seedlings (3% and 36%, respectively). The site has the second-tallest seedlings at 3.7 feet on average. This site received brushing as site prep for planting, and seedlings were mulched. Herbicide, brushing and mechanical blackberry control took place after plantings. The plantings were entirely potted, whereas most sites are a mix of potted and bare root stock. Notably, this site was watered in 2018, but not 2019. It also received compost blow-in of Cedar Grove product prior to installation. The site did receive weeding in 2019, especially to control bindweed cover.

Yesler Creek Headwaters / South Ravine Southend

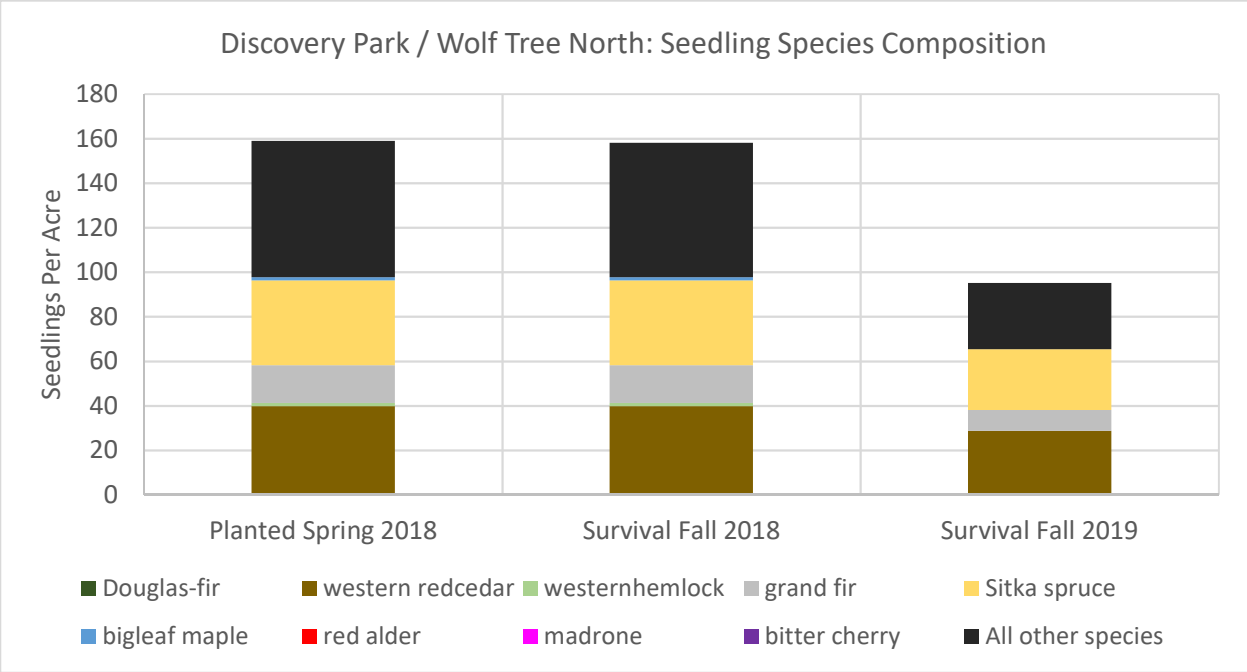


Yesler Creek Headwaters / South Ravine Southend: Live Seedling Species Composition (trees/acre)

Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	82	82	*0*	118	*0*	**0%**
THPL	81	81	*0*	72	*9*	**11%**
TSHE	61	54	*7*	55	*0*	**9%**
ABGR	130	130	*0*	126	*4*	**3%**
PISI	7	7	*0*	7	*0*	**0%**
ACMA	0	0	*0*	0	*0*	**NA**
ALRU	3	3	*0*	5	*0*	**0%**
ARME	0	0	*0*	0	*0*	**NA**
All Other	42	39	*3*	25	*15*	**41%**
Totals	**404**	**394**	***10***	**408**	***0***	**0%**

Yesler Creek zone South Ravine Southend had exceptional survival. Seedling density overall is high, but not unreasonable – at over 400 trees per acre, most are conifers. Soil pits installed at the permanent plots showed sandy soils, correlating with lower mortality. This site has a mostly open canopy (35% closure) and very open vegetation layers (1% cover tall vegetation, and 29% short vegetation). The seedlings at this site have been well taken care of. All seedlings were potted, rather than a mix of potted and bare root like most sites. This site received brushing as site prep for planting. Seedlings were mulched, and the crew also incorporated the wood chip mulch with native soil when backfilling the holes at this site. Brushing and mechanical invasive plant control took place after plantings. Seedlings at this site were watered in both 2018 and 2019. Variability in the sampling between 2018 and 2019 resulted in more Douglas-fir observed in 2019 than in 2018; no additional planting took place.

Discovery Park / Wolf Tree North



Discovery Park / Wolf Tree North: Live Seedling Species Composition (trees/acre)						
Species	As Planted Spring 2018	Survival Fall 2018	*Died summer 2018*	Survival Fall 2019	*Died 2018-2019*	Total Mortality
PSME	0	0	*0*	0	*0*	**NA**
THPL	40	40	*0*	29	*11*	**28%**
TSHE	2	2	*0*	0	*2*	**100%**
ABGR	17	17	*0*	9	*8*	**45%**
PISI	38	38	*0*	27	*11*	**28%**
ACMA	2	2	*0*	0	*2*	**100%**
ALRU	0	0	*0*	0	*0*	**NA**
ARME	0	0	*0*	0	*0*	**NA**
All Other	61	60	*1*	30	*31*	**51%**
Totals	**159**	**158**	***1***	**95**	***63***	**40%**

Discovery Park zone Wolf Tree North had good seedling survival. Western redcedar and Sitka spruce had acceptable survival rates. Broadleaf small trees, mostly cascara, experienced substantial mortality. Soil pits installed at the permanent plots showed sandy soils, correlating with lower mortality. This site has a moderately closed canopy (62% closure) with dense tall and short vegetation (71% and 55%, respectively). This site received invasive plant removal prior to planting. Soil moisture is fairly high here, so the site did not receive mulch or watering. All seedlings were potted stock. No follow-up treatments took place in 2019.

VIII. Ecological Condition

Seedling planting projects are developed to improve the ecological condition of a site. Seedling survival is a crucial piece of the success of the projects, but should be considered in the context of overall seedling density and species composition including natural regeneration and plantings from previous projects. Future management recommendations will depend on the site characteristics, regardless of whether seedlings were planted in 2018 or established in other ways. Furthermore, as time goes on it will become more difficult to track individual seedlings from the 2018 planting. Quantifying the total picture of seedlings as they transition to small trees will allow SPR to understand the success of planting projects over longer timeframes.

Figure 4 shows the range of conditions in the zones, including seedlings planted in 2018 and seedlings that established in other ways. PPGS2, AW2, and Schmitz Blvd Slope have extreme seedling densities above 800 TPA, dominated by broadleaf species. Competitive mortality of the seedlings is nearly certain, with conifer seedlings usually dying under the shade of the rapidly-growing broadleaf species. Without thinning the broadleaf species back, continued loss of the conifer cohort is likely. Densities more than 400 TPA in open canopy conditions are likely to suffer competition-related mortality. In closed canopies, densities above 200 TPA are likely too high.

Zones 3A, Maduzia Gap, and PPGS3 have acceptable overall seedling densities, but the proportion of broadleaf is high. These sites may benefit from cutting back broadleaf species where they compete with conifers, if conifer regeneration is the goal. In these sites, much of the broadleaf component is from regenerating bigleaf maple stump sprouts that grow densely but in a limited area. The overall impact of infrequent maple stump sprout clumps is not damaging to the site as a whole. SPR could consider coppicing stump sprouts to allow one or a few main leaders to develop into larger-diameter trees, rather than several small-diameter trunks with low ecological value in the long-term.

South Ravine Southend has a robust conifer cohort at the outer limits of acceptable density. SPR should continue to monitor this site; thinning these conifers at around age 10 to 15 (year 2028 to 2033) to around 200 TPA will increase the health and vigor of the remaining trees. Otherwise, these trees will compete with each other for light and water, limiting health and growth of all trees.

Chicago and Wolf Tree North have a good species composition but are somewhat under-stocked for the light conditions. Chicago in particular could support more seedling density given its mostly open canopy. Additional plantings here would help the long-term objectives of establishing diversity and new conifers.

Arroyos 47th Ave SW, Rose, and MF9 have lost nearly all their seedlings, planted or natural, and should be re-considered for new planting projects. All three of these sites have mostly closed canopies and dense competing vegetation; careful consideration of site prep, seedling species selection (i.e., shade tolerance), and dedicated seedling care including cutting cones of light and watering if possible, will probably be required on these difficult sites.

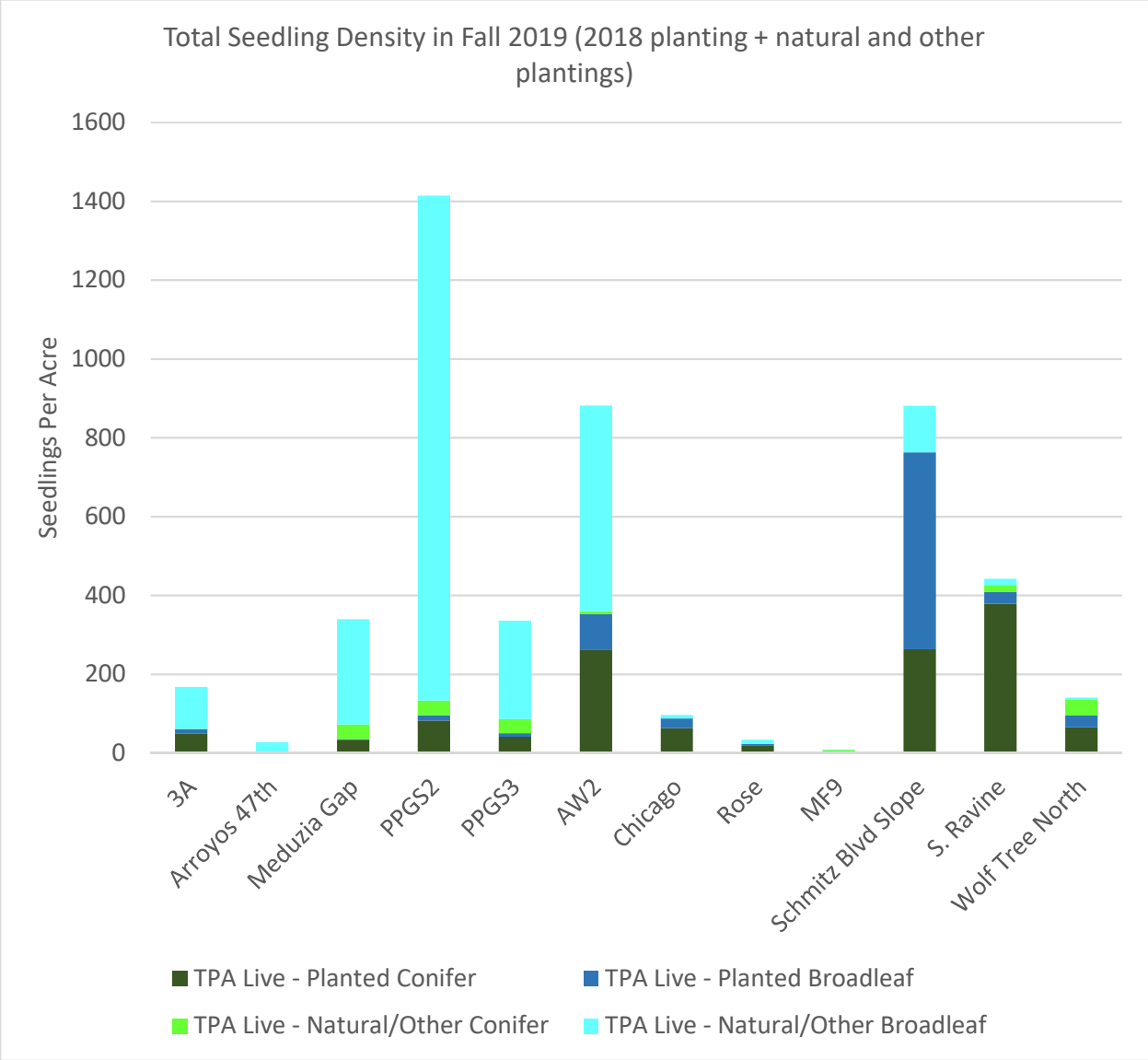



Figure 4: Total seedling density including trees planted in 2018, natural regeneration, and seedlings from previous planting projects.