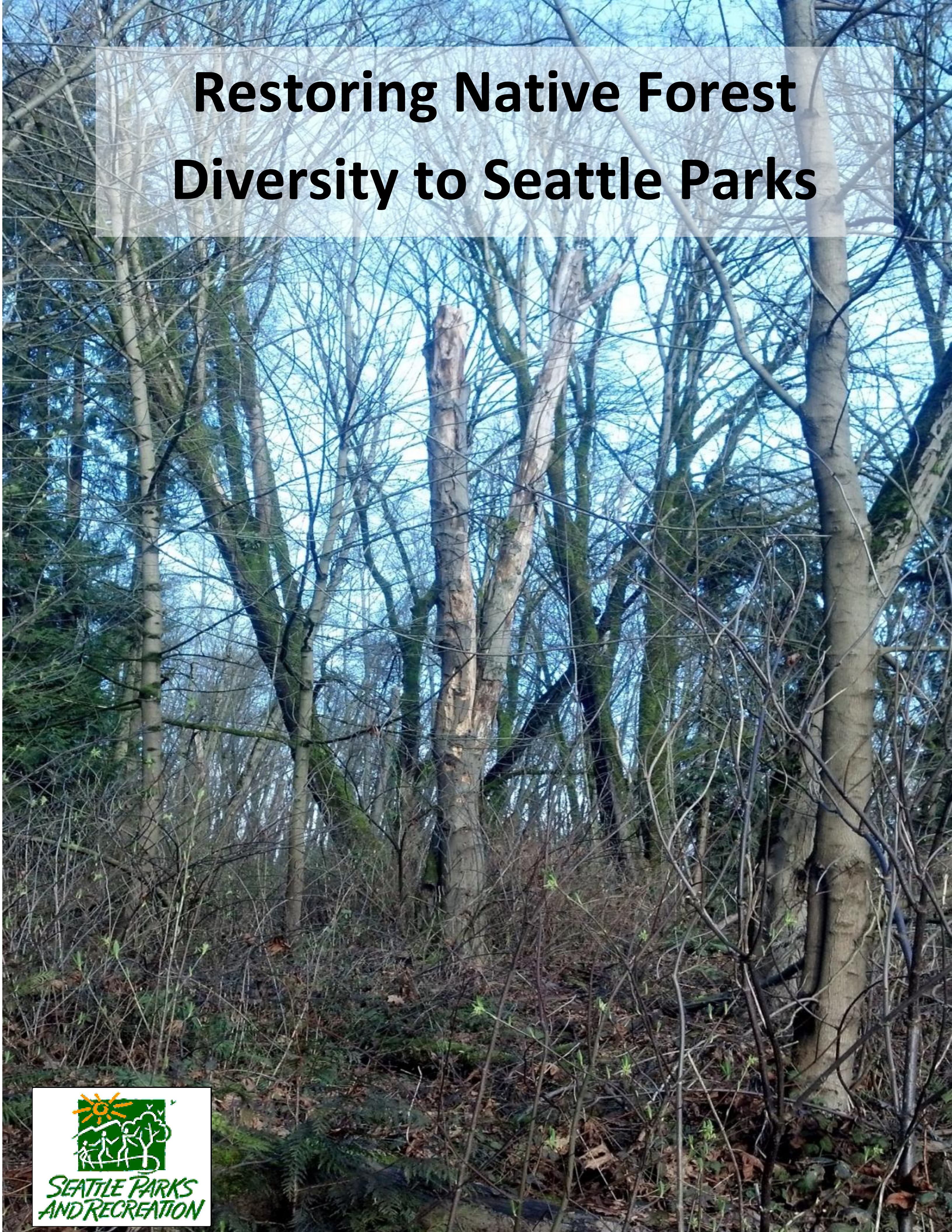
Restoring Native Forest Diversity to Seattle Parks



SEATTLE PARKS AND RECREATION

Restoring Native Forest Diversity to Seattle Parks

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Project summary

Seattle's forested parks provide many benefits for the environment and the community. Bald eagles, hawks, foxes, salamander, and other local wildlife rely on these urban refugia for habitat. The plants in the forest help to reduce storm water runoff, filter pollutants in the water, and reduce erosion. As these plants absorb carbon dioxide and other pollutants from the air, they also improve air quality and help reduce the effects of global warming. Studies have also shown that urban forests have positive health benefits ranging from asthma relief, improved academic performance, and shorter recovery times for patients. Yet many of these ecological functions and community benefits have been compromised due to a lack of understanding of how to properly steward urban forests for diversity and resilience. Consequently, many of Seattle's forested parks are awash with non-native invasive plants and the composition and diversity of native trees and shrubs has become dramatically simplified from their historic basis.

Northwest forests are typically made up of coniferous trees with a small mix of deciduous trees. At this time, only about 31 percent of the forests within Seattle's parks are comprised of conifers, while deciduous trees dominate 69 percent. Deciduous trees provide less shade and rainwater mitigation than conifers, which maintain their canopy year-round. Seattle's urban forests also lack age and species diversity. Because so many of the trees in Seattle's parks were established near the beginning of the 20th century, many, in particular hardwoods, are now in an advanced stage of decline.

Interest is growing amongst Seattle's urban park planners, as well as citizen volunteers, to restore the forests within Seattle's parks to the species and composition that are similar to pre-settlement conditions. However, it is widely acknowledged by studied planners that *the desired future condition is not the past*. Although many lessons can be learned by studying pre-settlement records of vegetation cover in the Seattle area, attempting to restore urban forested parks to the old-growth conditions of the past may not be practical in the face of an uncertain climate future. However, restoring urban forests with the notions of diversity and resilience in mind can lead to urban environments that are more adaptive and still provide many of the ecosystem functions of historic old-growth forests.

Since the 1990's, efforts to restore native tree and shrub diversity within the understory of mature red alder (*Alnus rubra*) and big leaf maple (*Acer macrophyllum*) dominated forests, such as at Carkeek Park and the West Duwamish Greenbelt, have had only minimal success. Due to intense shade competition from the dense canopy, as well as competition from dense understory vegetation, seedlings planted into the understory of these two parks have experienced mortality rates as high as 90 percent. Additionally, the red alder throughout these parks is reaching the end of its biological lifespan and beginning to decay. Without a well-established understory cohort to replace the dominant hardwoods, the future of the forests at these sites is questionable.

The issue of cost versus benefit inevitably becomes a driving factor when the scale of restoration reaches into the hundreds of acres. Employing city staff or private contractors is inordinately expensive, in particular when restoration efforts fail and projects need to be reinitiated anew. However, innovative planning that draws upon inspired citizen volunteers can dramatically reduce the largest cost factor in these projects – namely labor. Additionally, if decadent timber is proactively removed and sold, either as conventional logs to regional mills, or through more creative means such as auctions to local artisans and craftsmen, then revenue can be generated from restoration projects that can further offset costs. If unorthodox solutions such as these can become the hallmark of future restoration efforts, then scale becomes an insignificant issue and the only remaining barrier to success is political will.

Project purpose

This project evaluates the stand dynamics within the hardwood forests at Carkeek Park and the West Duwamish Greenbelt, and proposes management options for successfully reintroducing a broader range of native hardwoods and conifers.

Project objectives

The management recommendations in this paper are intended to address the following objectives:

1. Conserve wildlife habitat – Forest vegetation will be managed to preserve and enhance wildlife habitat.
2. Maintain buffering and aesthetic value – Forest vegetation will provide visual screening between the park and surrounding neighborhoods as well as provide an aesthetically pleasing environment for park users.
3. Mitigate urban pollution– Forest vegetation will trap air pollutants, provide biofiltration ofwater, screen excessive noise, and buffer urban microclimates.
4. Provide natural drainage – Forest vegetation will be managed to preserve and increase theland's ability to buffer and direct storm water.
5. Protect soil and water quality – Forest vegetation will be managed to preserve riparian corridors and hillsides by preventing erosion and maintaining vegetative cover.
6. Protect public safety – Forest vegetation will be managed to reduce the risk of hazards from trees.

Project locations

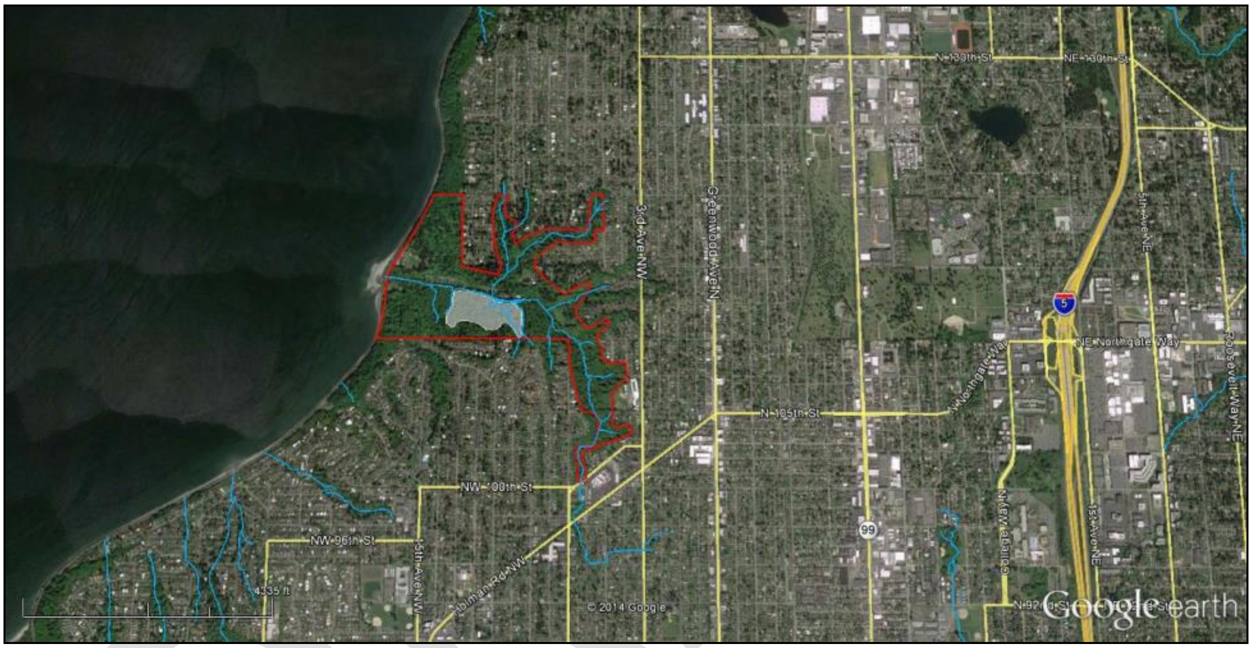
Carkeek

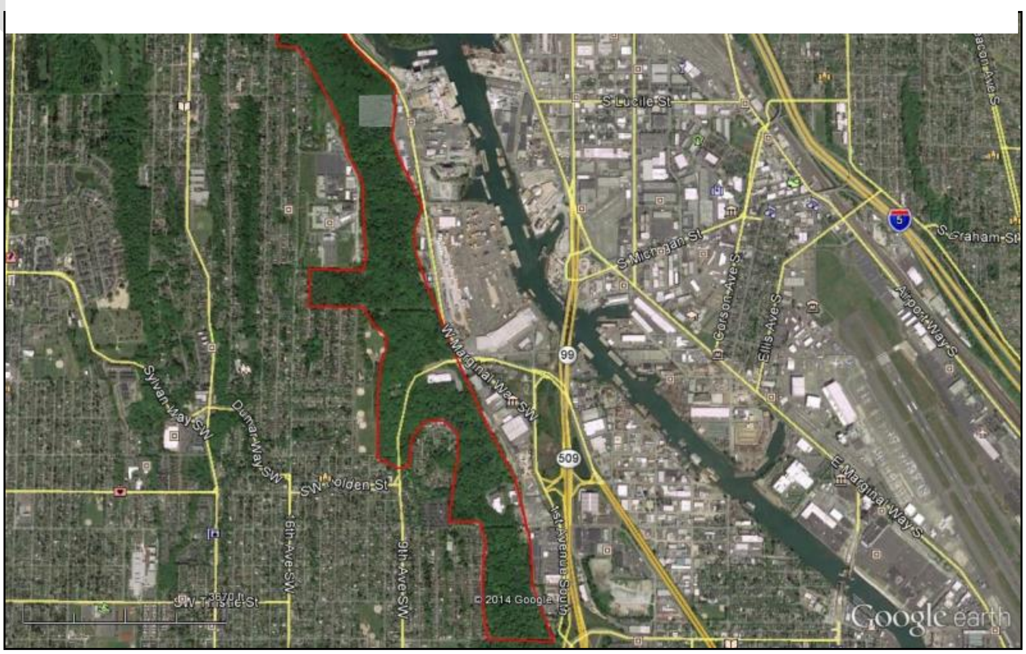
Carkeek Park is a 180-acre property situated in the Northwest Parks District. It encompasses a series of steep, forested ravines that cascade from close to 300 feet down to sea level. The park includes a number of creeks, the largest being Piper's Creek named after one of the pioneering families at the beginning of the 20th century. An estimated 150 acres is forested, the remaining 30 acres is wetlands, roads, meadows, play areas and beach. This project focuses on a 15.6-acre area of the forest on the north-facing slope above Piper's Creek.

West Duwamish Greenbelt

The West Duwamish Greenbelt is the largest contiguous greenbelt in Seattle, encompassing over 800 acres of forested public land. It was named after the Duwamish tribe that populated metropolitan Seattle before European colonization. The greenbelt encompasses the extended forest along the eastern slopes of West Seattle that is visible from I-5. The Greenbelt is home to fox, red-legged frogs, hawks, and bald eagles. There are ample easily accessible trails for walkers, hikers, and runners. This project focuses on an 8-acre area of the forest on the west side of the Duwamish River Valley near the north end of the Greenbelt.

Figure 1. Carkeek Park in Northwest Seattle. Project site highlighted within park.





History

Carkeek

After logging in the early 1900's land use at Carkeek was primarily agricultural: grasslands and orchards. Traces of a brick factory are still present; a fishing industry was situated on the beach. The Piper family had built an 80-acre family farm. Whereas, most of the Southwest corner of the park and upper reaches of the creek were used as pasture land. Vitamilk, a local dairy was located at the present site of Viewlands Elementary School. To the West of the canyon, cherry orchards had stretched from the Southern end of the park near the sound to the North Bluff. In addition to the Piper farm, the purchase had included a few other homesteads and a fishing operation named the Whiz Company. Today, the Piper Family orchards are maintained for cultural heritage.

After Carkeek Park was created in 1929 agricultural use was reduced and finally terminated. The area started the long process of forest regeneration with pioneer vegetations of red alder and big-leaf maple, interspersed with a few evergreen trees. Evergreen-dominated pockets developed near the North Meadow, the Environmental Learning Center, and the Norcross entrance. A generally dense undergrowth developed with native species like salmonberry, thimble- berry, sword fern, salal and others. When the surrounding plateaus were developed before and shortly after WW II, non-native garden species started to intrude into the park, some of which are invasive or noxious weeds. One invasive species, English Ivy, was planted on purpose to reduce erosion of the steep slopes!

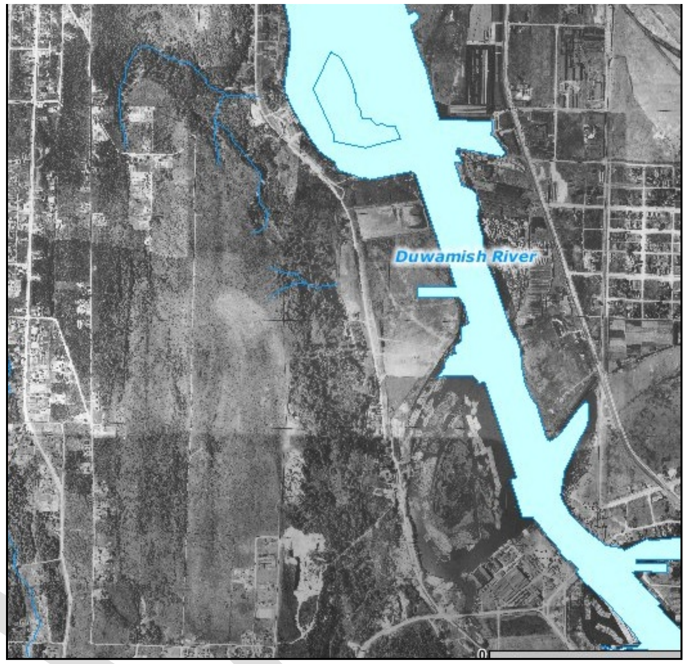
At the turn of the 20th century the 60–70 year-old forest is maturing and approaching its demise, literally "falling to pieces", creating small and large gaps in the canopy. In natural Pacific Northwest forest succession fallen trees would soon be replaced by the next, mostly evergreen, forest generation. However, in this urban forest, surrounded by urban neighborhoods and with a poor conifer seed source, this natural process has been disturbed and without intervention an invasive-dominated shrub canopy will develop instead.

Current Public Use

Carkeek Park is one of the most highly visited parks in the City of Seattle. The park park offers extraordinary views of Puget Sound and the Olympic Mountains, beach front access, children's play areas, and an Environmental Learning Center. Miles of hiking trails have been established throughout the forested areas of the park and these receive extensive year-round use.

West Duwamish Greenbelt

Prior to European settlement, this area was occupied by the Duwamish tribe. Around the turn of the century, it was logged by Seattle's early settlers. The City of Seattle purchased the Soundway property in the 1950’s and 1960’s for the subsequently cancelled Sound Way project that would have linked Seattle and Vashon Island by highway and bridge. In 2004, then mayor Greg Nickels proposed selling some of the property for housing, but the community wanted it all preserved. The City Council supported City retention of the Sound Way Property and gave the community time to raise funds to do so. The Nature Consortium, a nonprofit environmental arts organization, subsequently obtained funds from the State of Washington and contributions from the community, to preserve the Sound Way Property as open space.



Over the past 5 years, the Nature Consortium has had hundreds of work parties and planted over 10,000 trees and 13,000 shrubs and understory plants on the property.

Current Public Use

The project area in the Duwamish Greenbelt does not receive significant public use. Other than a single walking trail that meanders along the western boundary of the site, no other public use facilities or trails occur in this area and there was little evidence of public use beyond the trail.

Site Conditions

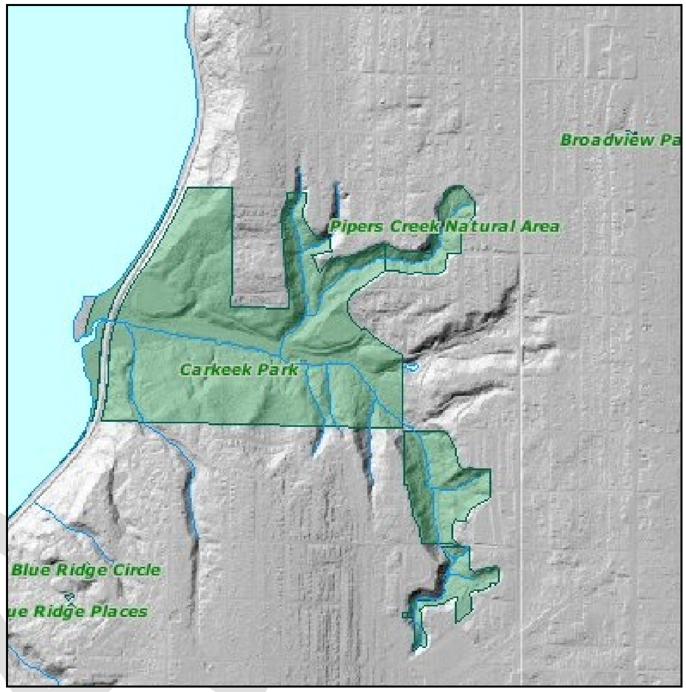
Topography

Carkeek

Physically, Carkeek Park is somewhat of an anomaly to the otherwise uniform Northwest Seattle landscape. This area generally tends to be flat and plateau-like, rising gently to a height of 500 feet. Over millennia though, the Piper's creek system, fed by water seeping from the extensive bog between present day Greenwood and 8th Avenues, has eroded down into the glacially deposited soil structure, developing a series of steep narrow ravines. The bulk of this ravine system today makes up Carkeek Park.

The project site occurs on a north-facing slope above Piper's Creek. Slopes in this area generally average between 30 - 40 percent and elevations range from 200 feet along the southern park property line to less than 100 feet where Piper's Creek runs along the base of the slope.

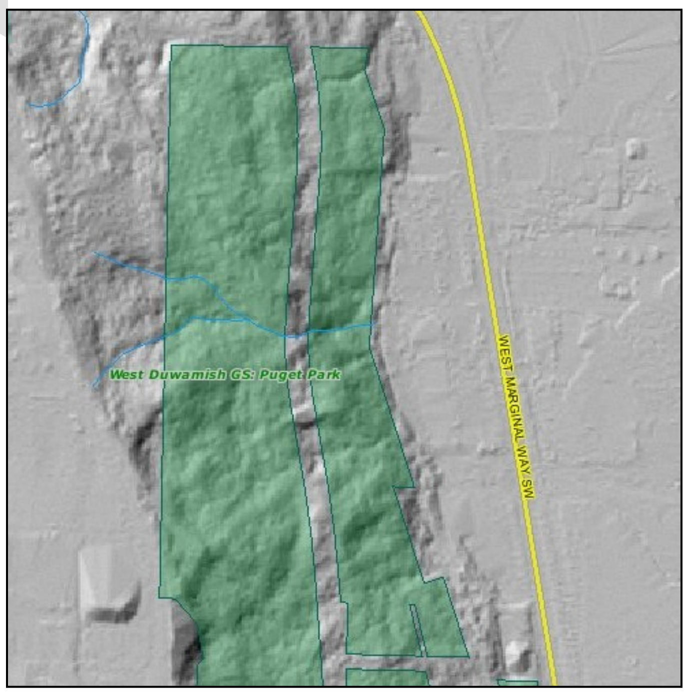
Figure 5: Hillshade photo showing landscape profile of Carkeek Park and surrounding area.



West Duwamish Greenbelt

The West Duwamish Greenbelt occupies an east-facing slope just above the floodplain of the Duwamish River. Elevations range from a height of 300 feet along the western park boundary to less than 100 feet along the base of the slope where it meets the floodplain. Slopes across the Greenbelt are moderate, averaging 30 – 40 percent. Multiple small "benches" typify the slope profile, and these benches retain higher amounts of soil moisture and small forested wetlands.

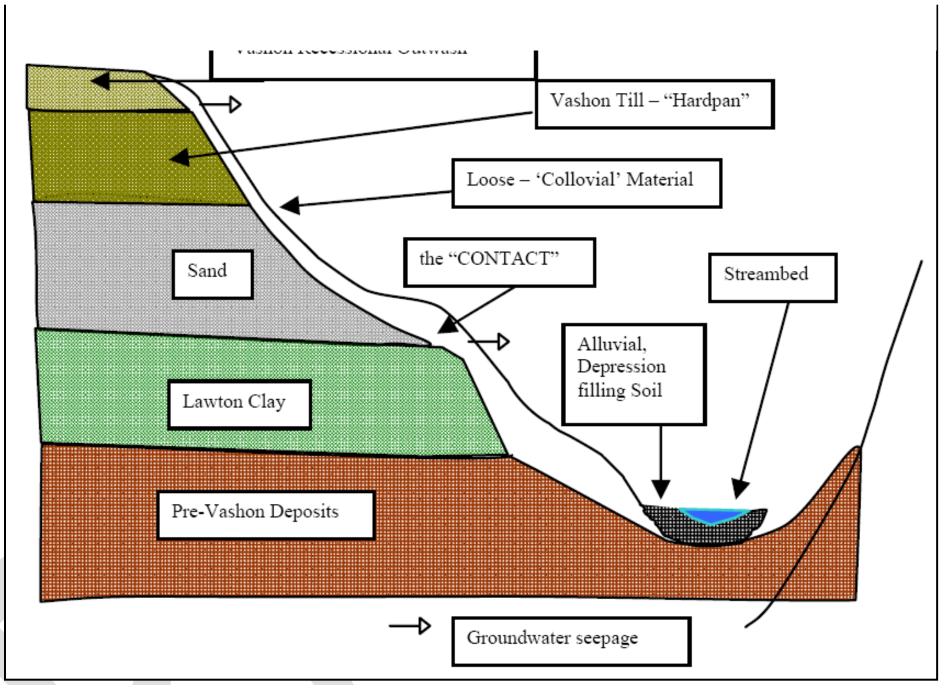
Figure 2: Hillshade photo showing landscape profile of the northern portion of the West Duwamish Greenbelt.



Soils

Deep soil coring in the region reveals soil layers of non-glacial clay/silt, underlying glacially deposited layers of clay-silt with sand pockets, gravely-sand, and sandy-gravel/silt with lobes of clay. The top layer is subdivided with the last and uppermost material deposited having not been glacially overridden. Thus, the soil crust tends to be fairly loose and permeable while the lower layers are some of the densest soil types in the world (Waldron 1962). The Seattle area also contains recently deposited soils. These are Colluvial, Alluvial and Depression-Filling soils.

The first of these, Colluvial, is described as a gravitationally driven accumulation of fallen material. It covers the sides and accumulates at the toes of slopes through soil creep, superficial sloughing, land sliding and slope wash. By nature Colluvial soil in both Carkeek Park and the West Duwamish Greenbelt tends to be "soft to medium, dense to soft to stiff" (Shannon 2000).



The next two soil types, Alluvial and Depression-filling, are water driven. Alluvium is a water deposited material associated with riparian areas. It consists mainly of silt, sand and gravel, but may also contain organic material (Waldron 1962). Depression filling soil is a combination of clay, silt and organic materials. Most depression filling soils are found on upper ridges, plateaus, or as part of river alluvium. Depression Filling soils are associated with wetland habitats (Shannon 2000).

Landslides

The soil profiles across both Carkeek Park and the West Duwamish Greenbelt are prone to soil creep and occasional landslides, in particular on slopes that exceed 40 percent. Minor landslides have occurred in the past, however, those that occur today tend to be superficial, with deep seated movements happening rarely. Most slides in the past are of a type known as "colluvial". They tend to consist of shallow, superficial sloughing of loose material (Shannon 2000). Donald Tubbs found, in 1975, that slides were most likely to occur at the contact point between the upper sand layer and underlying Lawton Clay or Pre-Vashon Sediments on greater than 15 percent slopes (Tubbs 1975).

Hydrology

Soils on the slopes at both parks tend to be very wet to saturated during winter months. Salmonberry, the dominant understory vegetation at both parks, is an indicator of perennially wet soils. Given its polar aspect, the slopes comprising the project area at Carkeek Park retain moisture much later into the season than at the West Duwamish Greenbelt. The slopes at the park are also characterized by deeply incised seasonal stream channels that drain down to Piper's Creek. Slopes at both parks have a varied topography with multiple "benches" that capture and retain soil moisture in small forested wetlands.

Figure 5: Streams

The project site at Carkeek Park hosts three seasonal streams that flow down to Piper's Creek. Two additional seasonal streams are immediately adjacent to the project site on both its west and east sides. The streams cascade down at a relatively steep gradient and have deeply incised channels. During the site assessment in February 2014, the flow rate of the streams was moderate, turbidity was low and the water appeared clear and clean. Fine gravels comprised the stream beds.

Although there are no mapped streams at the project site at the West Duwamish Greenbelt, a small seasonal stream was found during the site assessment near the northeast corner of the site. The stream was draining a small forested wetland, flowing less than 100 feet before leaving the park's eastern boundary.

Soils at both sites have a significant influence on the role water plays in these forests. The top layer of soil is highly permeable. However, underlying soil layers are extremely dense. Therefore, the top soil horizon is quick to saturate in the fall when winter rains return, and runoff is very high through the wet season. When saturated, the loose colluvial soils comprising the top horizon are prone to creeping, slumping and sliding, depending on the steepness of the slope. The flow rate of the seasonal streams at Carkeek Park are likely “flashy”, with surges of water immediately following heavy rainfall. This is evident in some of the stream ravines by the deep incutting and bank erosion.

Hardwood dominated forests in the Northwest are generally less capable of retaining and utilizing soil moisture in the winter months as transpiration shuts down during the trees dormancy. This can increase the “flashy” character of streams and further exacerbate soil movement. However, despite the shade value of north and east-facing slopes beneath dense canopies, there can be extreme competition for soil moisture during summer months due to shallow soils that have limited capacity to retain water and dense, shallow-rooted understory vegetation that has a hig h demand for water during the growing season.

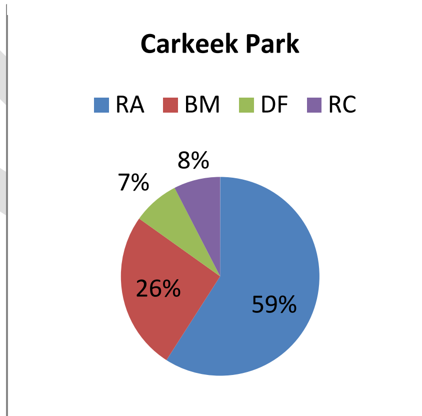
Riparian cover over and adjacent to the seasonal streams at Carkeek Park was very minimal and chiefly comprised of salmonberry. There was a conspicuous absence of tree cover along the majority of the extent of each of the seasonal streams, thereby creating significant gaps in the forest canopy that run on a north-south axis. The likely cause of this lack of tree cover is the presence of mountain beaver tunnels within immediate proximity of the streams. Mountain beavers can damage the roots of trees as well as increase soil instability, in particular on steep slopes, leading to early blowdown of trees.

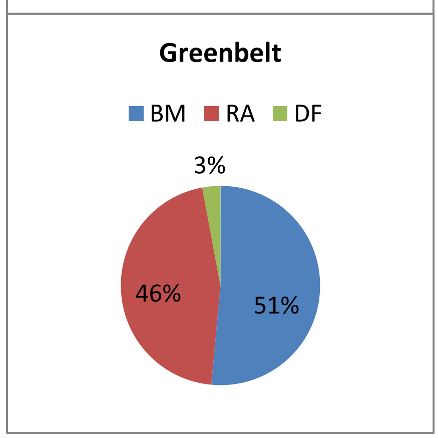
Forest Composition

On February 11th and 12th, 2014 transects were made at both project sites to collect forest inventory data and evaluate general forest structure and health. 1/10th acre (37.2' radius) inventory plots were installed at regular intervals along the transects, and the following quantitative and qualitative measurements were documented:

1. Tree species
2. Tree diameter
3. Tree height
4. Live crown ratio
5. Understory tree seedling regeneration
6. Understory shrub species and composition
7. Presence/absence of snags and downed logs
8. Invasive species
9. Forest structure
10. Forest health

In general, the forests within the project sites can be described as mixed deciduous stands dominated by mature red alder and big leaf maple that contain small patches of mature conifers, primarily Douglas fir (*Pseudotsuga menziesii*) and western red cedar (*Thuja plicata*). Mature conifers also occur as individuals scattered throughout each site. The stocking density of dominant trees varies significantly across each site. Stocking at Carkeek ranges from 40 – 80 trees per acre (tpa) with an average of 60 tpa. Stocking at the West Duwamish Greenbelt ranges from 60 – 130 tpa with an average of 76 tpa. Red alder is the dominant species at Carkeek Park, comprising nearly 60 percent of the total stocking, followed by big leaf maple at 26 percent and equal representation of Douglas fir and Western red cedar (though the latter tends to be younger regeneration versus mature dominant trees). Although red alder is the dominant tree species in the canopy at the West Duwamish Greenbelt, big leaf maple is the more abundant species, primarily due to natural regeneration in the understory. Based on total stocking, big leaf maple comprises 51 percent of the stand, followed by red alder at 46 percent and Douglas fir at 3 percent.





Although there is a significant range in the diameters of trees at each site, the majority of the dominant trees fall within 16 – 25 inches diameter at breast height (dbh). Given the fairly uniform height amongst all of the hardwoods, it can be assumed that the majority of the trees likely naturally regenerated on disturbed soils at approximately the same time, presumably after active agricultural management at the site ended. As the alder stand developed over time, competition between individuals led to slight differentiation in canopy dominance and crown development. Trees that were less competitive have a smaller live crown ratio (LCR), the total height of the tree that is in live crown, and smaller diameters than trees occupying a more prominent place in the canopy. The forest at Carkeek Park is slightly older than the forest along the Greenbelt, and the trees at the former site have grown under competition for a greater period of time. This has produced trees that are much taller than their counterparts at the Greenbelt, although diameters are approximately the same. Therefore, the taller trees at Carkeek have a much higher height:diameter ratio (HDR) than those along the Greenbelt. In general, trees with an HDR of 75 or greater are more susceptible to wind or ice storm damage than trees with greater girth compared to their height. At Carkeek Park, the combination of advanced age and the high HDR have created very unstable stand conditions that has led to a significant

Figure 11: Tree diameter distribution

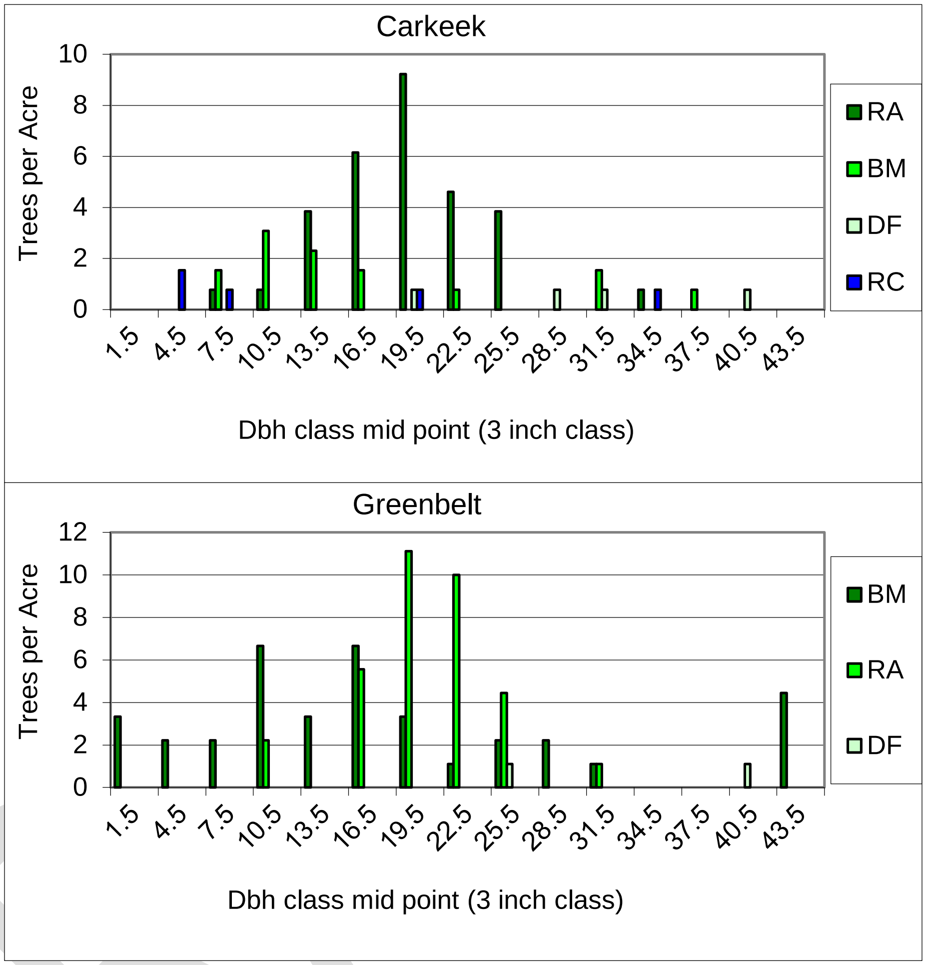


Figure 12: Example of red alder dominated site with significant blowdown in foreground.

number of snapped trunks and naturally felled trees. Personal observations indicate that most naturally felled trees occur once trees have fully leafed out, rather than from blowdown during high winds (Marjon 2014). This further supports the assumption that the high HDR has created a stand condition where trees are unable to support their heavy crowns. This process is quickly reducing stand density and opening the canopy of the forest. Understory brush species, in particular salmonberry, has responded vigorously to the influx of light through the canopy. However, the increasingly dense understory brush is creating another low canopy layer that is further suppressing the ability of conifers to naturally regenerate.

The following charts provide a summary of the basic forest metrics documented during the inventory and assessment process:

Figure 13: Carkeek Park Stand Summary

Dominant Species	TPA	Average DBH	Average Height	Average LCR	Average Volume Per Acre	Average BA	Average HDR
Red alder Big leaf maple	60	20”	120’	30%	33 MBF	142 sq. ft.	78

Figure 14: Wester Duwamish Greenbelt Stand Summary

Dominant Species	TPA	Average DBH	Average Height	Average LCR	Average Volume Per Acre	Average BA	Average HDR
Red alder Big leaf maple	76	20”	82’	35%	25 MBF	188 sq. ft.	51

Forest Canopy

The composition of the forest canopies at both Carkeek Park and the West Duwamish Greenbelt also has common characteristics. Red alder is the dominant species in both canopies, although big leaf maple is more prominent along the Greenbelt than at Carkeek. There is limited vertical diversity in the canopy at either park, given that the majority of the forests at both parks is dominated by a single cohort of alder. Big leaf maple, given its bulk when older, occupies multiple strata in the forest canopy. Additionally, a very few scattered older Douglas fir provide modest vertical structure above the canopy of the alder. Equally, a very few scattered naturally regenerated cedar, hemlock and maple provide modest vertical structure below the canopy of the alder.

There is significant variability in the horizontal structure of both canopies. On average, there is approximately 80 percent canopy closure across both sites. However, areas of lower density or where alder crowns are beginning to fail, have created greater canopy transparency. Additionally, there are frequent canopy gaps across both sites that average less than 0.25 - 0.5 acres in size. At Carkeek Park, canopy gaps total approximately 1.5 acres or 10.5 percent of the canopy, whereas canopy gaps only accounted for approximately 0.5 acres, or six percent of the canopy at the project site within the West Duwamish Greenbelt. At both sites, the creation of canopy gaps primarily occurs when groups of trees naturally fall down due to their heavy crowns or blowdown. This process also appears to be most common on wetter sites, or along stream corridors. Canopy gaps may be ephemeral within these stands as alder trees along the edges of the gaps at Carkeek Park showed signs of *plasticity* as they leaned towards the gap in order to optimize access to sunlight. Further, gap locations and sizes may change over time as older gaps close in due to plasticity of edge trees and blowdown of individuals or groups of trees elsewhere in the stand.

Red alder at both sites can be considered “overmature”, meaning that it has reached the extent of its biological lifespan and is going into a state of senescence. Tops of trees are dying back, blow downs are frequent and snags of various sizes and stages of decomposition are common. Although much longer lived, some of the mature big leaf maple at both sites is also showing signs of decline with dying tops. It was observed that both red alder and big leaf maple appeared to be more intact and in a healthier state along the lower slopes at Carkeek Park than on the mid or upper slopes. This is likely due to more abundant soil moisture lower in the landscape profile throughout the year, as contrasted with increased moisture competition and droughtiness on the upper slopes during summer months. Approximately 3.75 acres across the upper slopes of the project site at Carkeek Park, or nearly 25 percent of the site, was in a decadent state resulting in canopy transparency of approximately 30 percent. Approximately 1.5 acres, or approximately 20 percent of the canopy at the West Duwamish Greenbelt was either decadent or had low enough stocking to create canopy transparency of approximately 30 percent.

Figure 16: Canopy gaps (green) and sparse canopy (yellow).

There is little to no midstory in either of these stands. Over the intervening decades since the hardwoods naturally colonized each site, there has been very little natural regeneration of conifers to supply a second cohort in the understory. Comparatively, Carkeek Park had a higher level understory conifer development, with approximately three western red cedar of less than 10" DBH per acre documented during the inventory and stand assessment in January 2014. However, the Seattle Parks Department has indicated that these conifers are likely all that remain from a planting effort undertaken in 1995, and are not the result of natural understory regeneration. No conifers were documented in the understory at the Greenbelt.

The lack of natural conifer regeneration can be attributed to multiple factors, including: mountain beaver predation, shade suppression from both overstory and understory canopies, lack of downed wood and buried wood as a substrate for seed germination, lack of soil mychorhizzal associates due the length of time the stand has been under hardwood dominance, and the lack of seed source.

Big leaf maple regeneration was more abundant at each site, however, with five and fourteen saplings of less than 10" DBH per acre documented at Carkeek and the Greenbelt respectively. Natural regeneration of big leaf maple may be counterproductive to the objective of this project to foster the reinitiation of more diverse hardwood and conifer species in the understory. As the alder canopy declines, an increasing maple canopy can have a comparable, if not greater, suppressive effect on conifer regeneration.

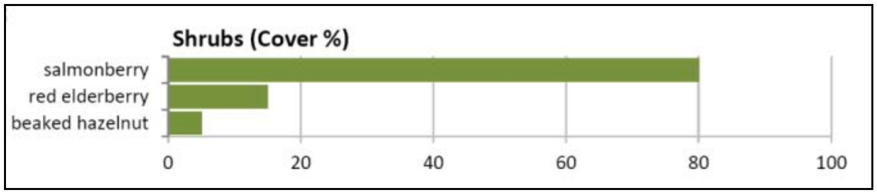
Understory vegetation

Both sites have a robust and relatively diverse complex of understory shrub species. Species composition and abundance varied significantly depending on elevation, with upland and drier sites having lower species diversity and a more open, less populated understory as compared to wetter sites lower on the landscape profile.

Salmonberry (*Rubus spectabilis*) is by far the most dominant species, and occurs in extremely dense patches that average six feet in height. Salmonberry was most abundant along lower slopes, on wetland benches and adjacent to streams, but was practically non-existent on upper slopes. The high density of salmonberry patches effectively creates a low canopy level in the forest strata that has a further suppressive effect on understory vegetation, ground covers and natural regeneration of tree seedlings. However, the deep root system of salmonberry can help also prevent erosion on steep slopes.

Other common, though less abundant species occupying wetter sites were red elderberry (*Sambucus racemosa*), sword fern (*Polystichum munitum*), and a limited amount of beaked hazelnut (*Corylus* *cornuta*). On upper slopes, Oregon grape (*Mahonia aquifolium*), Oso berry (*Oemleria cerasiformis*), ocean spray (*Holodiscus discolor*), and Nootka rose (*Rosa nutkana*) were more common.

Figure 18: Shrub cover by dominant species at Carkeek. GSP 2010.



Invasive species

Non-native and invasive species are present throughout both sites. Himalayan blackberry (*Rubus armeniacus*) and English ivy (*Hedera helix*) are the most common, with the former occurring in more open sites and along forest edges, and the latter occurring in deeper shade. Both species typically occurred in large patches, and where they occurred they were often competing heavily with other native vegetation. English ivy had the distinction of both colonizing the ground, and climbing tree trunks. Although no occurrence of this was found of this at either site, English ivy has the capacity, if left unchecked, to climb into the crown of trees and have a suppressive effect on crown foliage. Other species that occurred less abundantly, and more commonly as individuals, included: English holly (*Ilex aquifolium*) and English laurel (*Prunus laurocerasus*).

Figure 19: English ivy colonizing ground and climbing alder trees near Piper's Creek within Carkeek Park.

Mountain beaver

During the forest inventory and assessment conducted in February 2014, evidence of a robust mountain beaver (*Aplodontia rufa*) population was found throughout the project site at Carkeek Park in the form of subsurface tunnels and tunnel openings. No evidence of mountain beaver was found at the West Duwamish Greenbelt. Mountain beavers are typically found in coastal western hemlock forest zones. They are generalist herbivores, feeding on ferns, grasses, forbs, mosses, shrubs, hardwoods and softwoods. Mountain beaver require nearby water, either in the form of succulent plants or aquatic landscape components such as streams or wetlands. They also require well-developed shrub and forest canopies, such as those found in the park.

Mountain beavers are active during all hours but are rarely seen above ground. Signs of feeding and burrowing usually indicate their presence. Mountain beavers are typically found in forests dominated by Douglas-fir and western hemlock. They prefer moist sites that are not subject to continuous flooding but are not restricted to these areas, except in the most arid regions of their range. Mountain beavers prefer open or thinned stands where understory vegetation is prevalent; thus, commercial logging and reforestation sites often create very attractive habitat (Taylor 2013).

Mountain beavers build extensive underground burrows. These systems are typically 6 to 8 inches in diameter (considerably large for similar-sized burrowing animals) and can contain several passages, specialized chambers, and exits. The tunnels may be up to 10 feet underground but are often near the surface. Occasionally, these shallow tunnels collapse or break along the surface for short distances, creating a “surface run.” Their burrows may also reach the surface underneath logs or brush piles (Taylor 2013).

Figure 21: Aluminum flashing protecting cedar from mountain beaver damage (WDFW 2014).

Mountain Beavers cause damage to both young and mature trees. Damage to young trees can be identified as an oblique 45-degree cut through stems and branches up to one inch in diameter at ground level. Mountain beavers often clip conifer seedlings near the base, making it difficult to detect seedling predation (Taylor 2013).They can climb young saplings to a height of eight feet, cutting the side branches with the characteristic oblique cut. The animals also cause damage to roots by debarking and cutting the roots, which can also lead to plant destabilization. Mountain beavers can also undermine the roots of large, mature trees, leading to instability and increased chance of wind throw.

Control of mountain beaver damage is most effective when using an integrated management approach and combining multiple techniques to fit site-specific needs. The most common methods used to control mountain beaver damage are trapping, toxicants, exclusion, repellents, and habitat modification (Taylor 2013). In areas where individual small trees or shrubs are being damaged, seedlings can be surrounded with a 24-inch tall smooth cylinder, such as metal stovepipe, aluminum flashing, or rigid plastic tree tube (WDFW 2014).

Red Alder Stand Dynamics

Forest type and stand initiation

Red alder is one of the most common hardwood trees in the low elevation forests of western Washington. The range of red alder extends from California to southeast Alaska. Red alder grows in humid climates preferring moist, well-drained alluvial soils (Harrington 1990) with low winter temperatures, short growing season and lack of precipitation being the main limits to the range of red alder. It is mostly a lowland species commonly found within 125 miles of the seacoast at elevations below 2,400 feet. Historically, the distribution of red alder was limited to lower parts of valleys and it was mainly dependent on erosion on stream banks (Heusser 1964).

Red alder is a shade intolerant early successional species that it is found mostly on sites that have experienced disturbances such as clear cutting, farming and ranching, fire, flooding or landslides. Only after fire or other disturbances does it colonize uphill areas. Red alder seedlings thrive best when they germinate on bare, mineral soil, which accounts for its rapid emergence following logging and its presence on other disturbed sites such as landslides, roadcuts or areas subject to periodic flooding. However, red alder will rarely regenerate in the organic material found on the surface of undisturbed forest soils; nor will it grow in the shade. This means that in a mature alder forest, new alder seedlings do not usually replace the aging trees in the absence of a natural or human disturbance (Grotta 2009).

Red alder can colonize disturbed sites at a very high initial density that can exceed 800 tpa. In the first 15 years, alder grows so rapidly that virtually no other tree species can be maintained in the stand unless alder density is very low. Within this initial timeframe, the young stand quickly enters an initial stem exclusion phase and self-thinning begins reducing stand density. Early height growth of red alder exceed all other species in the Pacific Northwest except poplar species such as black cottonwood. A common species associated with red alder is big leaf maple. However, maple growth rates are greatly inferior to those of red alder. Therefore big leaf maple seldom become dominant among alders. Persistence of maple in shade, however, may cause it to outlive alder and become dominant later (Newton, M. and Cole, E.C. 1994).

Although it often competes with regenerating conifers due to its more rapid early growth, red alder can potentially enhance long-term site productivity and conifer growth by increasing soil nitrogen availability through its ability to fix atmospheric nitrogen (Miller and Murray, 1978). Because of its N-fixing ability, red alder can actually improve the growth of associated conifers on low-nitrogen sites, but in other cases it may lead to reduced growth compared with pure conifer stands (Puettman K.J. and Hibbs, D.E. 1996). Hardwoods enhance soil stability and soil and stream fertility in Pacific Northwest forests through N-fixation, production of high N-content litter, rapid regeneration after disturbance, and persistence in flood-prone and disturbed areas (Berg and Doerksen, 1975; DeBell, 1990; Trappe, 1968).

In the Pacific Northwest, hardwood dominant stands are important to the rate and direction of forest succession and regeneration following disturbance (Hemstrom and Logan 1986). They are hotspots for native biodiversity, providing food and cover for a variety of mammals, amphibians, invertebrates, and birds (McComb 1994), and are an important substrate for arboreal lichens and mosses (Peterson and McCune, 2001). Hardwoods stands are also associated with greater macroinvertebrate biomass in streams.

Red alder will increase the annual litterfall in mixed stands (Waring and Schlesinger 1985). Because of the increased amount and the higher nutrient concentration in red alder litter (Zavitkowski and Newton 1968; Gessel and Turner 1974; Cole et al. 1978), red alder will accelerate nutrient cycling in mixed stands (Bormann et al. 1994). Red alder litter, especially woody debris, initially decomposes faster than associated conifers (Neal et al. 1965). The decomposition rates of other litter mixed with red alder litter are also improved (Bormann and Sidle 1990). However, after the first year, litter decomposition rates slow down to rates similar to conifer litter (Edmonds 1980). Thus, red alder mixed with conifers can accelerate and improve the nutrient distribution within the soil profile and may also increase nutrient availability for the plants.

In comparison to many of our region's long-lived conifers, red alder has a relatively short lifespan. Although fast growing as a young tree, by 60 to 80 years the crown (branches and foliage) begins to break apart. By this time, when crown dieback exceeds new growth, red alder is considered to be in decline. In Washington, Oregon, and British Columbia, mortality of red alder increases rapidly in stands over 90 years old, and little alder remains by the age of 130 years (Newton and Cole 1994).The fate of a declining red alder forest is determined largely by the composition of its understory, or the trees and shrubs found in the lower layers of the forest. Sometimes, shade tolerant conifers, such as western red cedar, western hemlock, or Sitka spruce, are found scattered in and below the alder canopy. If so, then these trees may eventually become the dominant trees in the stand as the alder dies. However, stocking of these species may be low and uneven, and it may be many years before a new closed canopy emerges (Harrington 2006).

Many alder stands in western Oregon have few associated conifers, leading some researchers to conclude that those alder stands will be replaced by shrubs and that without disturbance a shrub-dominated community may persist for an extended period of time (Newton et al. 1968, Carlton 1988, Tappeiner et al. 1991, O'Dea 1992). Clonal shrubs, particularly salmonberry, but also thimbleberry and vine maple, often form a dense shrub canopy which makes it difficult for conifers to invade and become established from seed. These shrub species can expand rapidly by vegetative reproduction as space becomes available due to death of the alder overstory (Tappeiner et al. 1991, O'Dea 1992, Zasada et al. 1992).

Understory development

Understories of natural alder stands vary considerably with habitat type. In many cases, the understory of a mature alder forest is made up largely of shrubs without a significant conifer component (Hibbs and Bower 2001). Researchers have observed a variety of situations where the shrub layer may outlive the hardwoods, and perhaps even the conifers. In that event, the ultimate successional phase would be dominated by shrubs until large rotten logs from adjacent stands can provide a medium for encroachment of conifers. The brief life expectancy of alder snags and down logs apparently does not permit conifer recruitment (Newton, M. and Cole, E.C. 1994).

Salmonberry is one of the most common shrubs associated with alder forests, though vine maple, Himalayan and Trailing blackberry,Rred elderberry, and others are also found. Salmonberry is a clonal shrub and spreads via underground stems called rhizomes. It quickly colonizes moist soils following disturbance and can form a dense and continuous understory. Once established on a site, the rhizomes can occupy much of the space in the upper soil layer, making it extremely difficult for trees or other shrubs to establish without a severe disturbance and/or presence of pathogens and insects that severely reduce the bud ban in the ramets and rhizomes (Tappeiner et al. 1991).

The greatest obstacle for a free-growing conifer cohort is likely understory competition from Salmonberry. Salmonberry is an aggressive competitor that tends to increase in height and density after canopy removal (Haeussler et al. 1990). Moreover, salmonberry shows vigorous re-growth after manual brushing by re-sprouting from stem bases and rhizomes. Salmonberry can recover from brushing to pre-treatment height levels within one season.

Red alder and salmonberry can effectively out-compete conifer seedlings for light, water and nutrients. In some areas, alder have effectively suppressed conifer regeneration facilitating establishment of a salmonberry dominated regime. The lack of conifer regeneration and shrub-dominated plant communities in alder riparian forests have led some researchers to suggest that these stands will likely succeed to mostly treeless shrub-dominated communities (Minore and Weatherly 1994, Hibbs and Giorclano 1996. Pabst and Spies 1998. Hibbs and Bower 2001). Further, it has been suggested that a brush dominated site can suspend seral stage development by several hundred years (Central West Coast Forest Society 2014).

Shrub and herbaceous groundcover diversity can also be severely limited in dense alder stands. The ability of shrub and herb community to remain beneath alder is a function of overstory tree height and spacing. When the ratio of height to space between trees reaches 4:1 or more, shade intolerant understory species virtually disappear, and overall understory density decreases sharply (Newton, M. and Cole, E.C. 1994).

Natural conifer regeneration

The main conifer species associated with red alder in coastal areas are western hemlock, Sitka spruce, grand fir, western red cedar and Douglas fir. The characteristics that influence their presence in mixed stands are based on their silvics. These species have a medium (Douglas-fir), high (Sitka spruce, grand fir), or very high (western hemlock, western redcedar) shade tolerance. In addition, all these species have a slower initial growth but are longer lived than red alder (Burns and Honkala 1990).

Eventually, dense red alder thickets result in mortality of some or all conifers, leading to a pure red alder stand (Newton and Cole 1994). However, if the density of red alder is variable, the conifers can probably survive through the first two decades in the understory. Light availability is a good predictor of growth rates of many species regenerating in a variety of field conditions (Wright et al. 1998, Coates and Burton 1999). Creating canopy gaps in hardwood dominated systems in combination with other treatments can promote the microclimatic and site conditions conducive to successful conifer establishment and growth

(Chan et al. 1996, Slaney and Martin 1997). However, considerable uncertainty exists about what degree of thinning or opening creates light levels high enough to guarantee conifer survival and growth.

Canopy gaps of approximately one-quarter acre have been demonstrated to significantly increase the mean level of understory light from 16 to 30 percent of full sun (Drever 2005). Estimates of growth under these conditions can range from 6-10 inches per year for Douglas fir and approximately eight inches per year for grand fir and cedar. In a study of Douglas fir, western red cedar and grand fir planted in the understory of an approximately 50-year-old alder forest where such canopy gaps had been created, measurements of height growth two years after gap creation and planting corroborated these predicted values. Greater than 90 percent of seedlings survived and showed mean height growth of 13 inches (Douglas fir) and 16 inches (cedar and grand fir) after two years (Drever 2005).

Gaps of at least 20 feet in alder appear to be necessary for planted western hemlock to escape a long period of suppression. Even greater space is presumably required for natural conifer regeneration or intolerant planted conifers (Newton, M. and Cole, E.C. 1994). Western red cedar has been shown to approach its maximum radial and height growth rates at about 30 percent full sun (Drever, C. R., and K. P. Lertzman. 2001).

Salmonberry requires consistent brushing in order to minimize its competitiveness with conifer saplings. Successful control by manual brushing of salmonberry is possible with two or three treatments per year for several years (Haeussler et al. 1990). Increasing the frequency or number of brushing treatments will likely prevent salmonberry growth from negating the competitive advantage provided to the planted conifers by creation of canopy gaps (Drever 2005). A "free-to-grow" status for trees is deemed to occur when trees are three feet taller than competing vegetation (von Shilling and Buck 1999). If the mean height for competing shrubs measured before brushing is approximately six feet, then a free-to-grow status would be obtained when trees reach nine feet in height. At the predicted growth rates described above, conifer regeneration will achieve free-to-grow status after approximately 15 years.

These growth rates are clearly subjective to the site and may vary considerably depending on slope aspect, light availability, soil moisture and fertility, consistency of brush abatement and other variables. Seedlings planted at Carkeek Park, for instance, where brush was consistently cut back, reached the median height of surrounding vegetation within only seven years (Morjan 2014).

At the age of 25-40 years, provided the conifers have been suppressed severely, their height growth paths tend to intersect those of the hardwoods. If the conifers survive to this stage, the prognosis for their development improves radically. After the age of 40 years when alder height becomes static, low-density Pacific coastal conifer stands still have great potential for height increases and crown spread. What might have been described as a pure stand of alder at age 25 becomes a mixed stand of alder/conifer (Newton, M. and Cole, E.C. 1994).

Understory Tree & Shrub Establishment Strategies

As has been documented in the prior discussion of red alder stand dynamics, the establishment of a successful new cohort in the understory is dependent on the following variables: canopy transparency, controlling competing vegetation, adequate stocking density of seedlings and preventing animal damage. Each of these issues will be addressed in order.

Canopy transparency

Survival and growth rates of trees and shrubs planted beneath alder canopies can be significantly improved when canopy transparency is increased to at least 30 percent. This level of canopy transparency has been proven possible through creation of canopy gaps of at least 1/4 acre in size. It is also possible to achieve similar results through thinning the alder stand, or girdling trees, to the extent necessary to reduce overall canopy density to less than 70 percent. However, even at advanced ages, crowns on individual red alder trees are capable of rebuilding, or stems may show sufficient plasticity, to eventually fill in small gaps in the forest canopy.

The following strategies are recommended at both Carkeek Park and the West Duwamish Greenbelt to create and maintain a minimum canopy transparency of 30 percent:

1. Enhance existing gaps by felling or girdling hardwood trees (see note below on girdling) around perimeter of gap to the extent necessary to create a minimum gap size of 0.5 acres. Focus thinning along south side of existing gap in order to optimize sunlight penetration to the forest floor.
2. Create canopy gaps of 0.5 – 1.0 acres in size by felling or girdling all hardwoods in discrete patches scattered throughout the site. The number of trees required to be felled or girdled can be minimized by targeted lower-stocked areas of the stand for gap creation. Gap creation may require cutting up to 25 – 50 contiguous trees per gap at the West Duwamish Greenbelt and 38 – 76 contiguous dominant trees per gap at Carkeek Park depending on gap size. There should be no more than 3 - 5 gaps, depending on size, either naturally occurring or created, throughout the West Duwamish Greenbelt project site (8 acres), and no more than 4 – 8 throughout the Carkeek Park project site.
3. Fell or girdle 30 percent of the dominant and co-dominant hardwoods throughout the remainder of each site. Target the healthiest and most robust alders within the stand for felling or girdling. Retaining the trees in the most advanced stages of senescence will minimize the extent to which leave trees rebuild their crowns or exhibit plasticity and move to close in current canopy gaps. To the extent practical, felled trees should be dropped across slope to aid in erosion control. Trunks and large limbs should be left intact. Smaller branches should be bucked into pieces no longer than four feet in order to aid in replanting efforts. No more than 10 trees per acre should be girdled. Trees to be girdled should have two parallel lines cut around the circumference of their trunk 2 – 3 feet above ground with a chainsaw. Cuts should be deep enough to sever the cambium layer of the tree. Target big leaf maple for felling or girdling and reduce maple stocking to no more than five per acre. Given the excessive biomass contained in

the crowns of dominant big leaf maple, the most dominant trees should be retained and co-dominant or suppressed maple selected for felling or girdling. Retain all conifers and pre-existing snags.

4. Monitor natural understory regeneration of big leaf maple. Proactively thin naturally regenerating maple to no more than 25 trees per acre in order to minimize its future potential to establish a new canopy above conifer seedlings.
5. Annually monitor gap size and canopy density. Fell or girdle alders along edges that show excessive plasticity and threaten to minimize gap size, as well as select alders throughout stand to the extent necessary to maintain a maximum of 70 percent canopy cover.

Girdling trees

Girdling trees for the purposes of creating snags warrants further discussion as there are implications to this strategy that are unique in urban parks that receive heavy use by recreationists. The following present key factors that should be considered when deciding whether, when and where to create snags:

1. The most effective means to creating long-lasting snags is to top a tree, rather than girdle. Ideally trees should be topped at a minimum height of 20 feet from the ground. However, tree topping can be expensive, therefore girdling creates a second option. Snags created by girdling typically do not have the longevity of topped trees, as the point of girdling creates a weak area in the tree that rots fast and causes the tree to fall.
2. Trees selected for snag creation should be well away from any trail or area of human use. Areas suitable for snag creation in urban parks include steep ravines, wetlands, riparian zones adjacent to streams (in particular if tree is leaning towards stream), and other sensitive sites less frequented by humans.
3. Trees selected for snag creation should be located in such a way that they will have minimal impact on trees and shrubs that were planted in the understory when they do fall. Trees that lean away from planted sites, or that have a predictable falling path where trees and shrubs have not been planted, are best for selection.

Controlling Competing Vegetation

Salmonberry requires consistent brushing or annual herbicide applications in order to minimize its competitiveness with conifer saplings. Salmonberry and other competing vegetation surrounding each tree seedling will need to be controlled within a sufficient distance of each seedling in order to allow sunlight to reach the tree. Competing vegetation will need to be controlled until each tree seedling has achieved free-to-grow status above surrounding vegetation.

Salmonberry, and other understory species and groundcovers, play important ecological roles such as erosion control, soil stability and the provision of forage for wildlife. Therefore, when controlling understory vegetation for the purposes of establishing other conifer and hardwood species, care should be given to only treat as much vegetation as necessary to support the establishment and growth of tree seedlings. Complete eradication of understory vegetation is counterproductive to the objective of restoring native species diversity within the forest.

The following strategies are recommended at both Carkeek Park and the West Duwamish Greenbelt to control salmonberry and other competing vegetation

1. Hand-slash: prior to planting (fall or early winter), competing vegetation should be cut back within at least a two-foot radius of each planting spot, or to the extent necessary to create a 45-degree cone of light around each seedling. For low-growing shrubs (e.g. sword fern, Salal, etc.) this may result in a four foot wide gap. For taller shrubs (e.g. salmonberry, elderberry) this may result in gaps wider than 10 feet. The planting site should be scarified to bare soil using a pick-axe, hoe dad, or similar tool. All plants will either be cut flush with the ground or their roots removed from the planting site. Vegetation should be chopped into pieces of less than 12 inches and scattered around the tree seedling in order to facilitate easier planting of the tree seedling.
2. Herbicide: as an alternative to hand-slashing, herbicide applications may provide a more cost-effective method for controlling competing vegetation. Initially, a combination of hand-slashing and herbicide use may be necessary to prepare a site for planting. Once seedlings are in the ground, herbicide-only follow up may be possible to continue to control competing vegetation in subsequent years. If herbicides are to be used, they should be applied in a targeted manner to vegetation within the immediate vicinity of the planting site, versus applied broad scale to all understory vegetation throughout the stand.
3. Continue to cut back or apply herbicides to competing vegetation during subsequent seasons until trees achieve a “free-to-grow” status of three feet above competing vegetation. This may require trees to reach 6 – 10 feet in height and take a period of 5-10 years. Vegetation should be cut back in early summer after the initial growth phase of shrubs and ground covers has completed (typically late June/early July). A good indicator of proper timing for brush control is shortly after sword ferns have completely unfurled. In order to minimize disturbance of bird nesting sites, the area should be monitored to ensure that chicks have fledged and nests are no longer being occupied.

Planting conifers and hardwoods

The long-term objective for each site is to achieve a minimum survival rate of 100 conifers and 50 hardwood trees and shrubs per acre of the seedlings planted. Therefore, 300 seedlings per acre (200 conifer & 100 hardwood) will be evenly distributed throughout the site with the expectation of 50 percent mortality due to animal browse, drought, collapsing hardwoods and other factors. Seedlings will be planted on approximately a 12-foot spacing, with no conifer seedling being placed closer than 10 feet to an existing tree. A fertilizer packet will be placed in the planting hole of each conifer prior to planting. Where mountain beavers are present, solid plastic tree protectors will be placed around all seedlings. To aid in finding seedlings during subsequent competing vegetation control actions, each seedling will be flagged with a brightly colored ribbon tied to a stake.

Conifers

Conifer species suited to the two project sites include the following:

Table 1: Conifer species suited for project sites

Common name	Botanical name
Douglas fir	Pseudotsuga menziesii var menziesii
Western hemlock	Tsuga heterophylla
Western red cedar	Thuja plicata
Grand fir	Abies grandis
Pacific yew	Taxus brevifolia

Hemlock, cedar, Grand fir and yew are considered very shade tolerant and will do well either beneath the canopy or within canopy gaps. Douglas fir is considered moderately shade tolerant, but should be limited to the north side of canopy gaps in order to optimize access to sunlight. Critical factors to ensuring the success of conifer seedlings in achieving a free-to-grow status above surrounding vegetation include: selecting seedling stock from a seed source suitable for the site (e.g. Coastal, < 1,000’), using the largest seedling stock available (min. P+1), installing a fertilizer packet with each seedling to optimize initial growth, installing tree protectors to alleviate browse by mountain beaver, and annually cutting back competing vegetation.

Hardwoods

There is a tremendously diverse palette of native hardwood trees and shrubs to select from that are suited to Seattle’s urban parks (see species list in Appendix I). Prior to selecting trees and shrubs for planting, an inventory of existing understory species should be made and the species to be planted should be selected based on their absence, or lack of abundance, in the forest.

Preventing animal damage

The sole animal competitor for tree seedlings at Carkeek Park is mountain beaver. No evidence was found of significant animal competition along the West Duwamish Greenbelt. Mountain beaver can cause significant mortality amongst newly planted conifer seedlings as they both eat tree roots and can girdle or completely sever seedlings up to one inch in diameter, as well as climb young trees and eat the side branches. Mountain beaver typically grow to an average length of 14 inches.

Control of mountain beaver damage is most effective when using an integrated management approach. Methods to control mountain beaver damage include: trapping, toxicants, exclusion, repellents, and habitat modification. Of these five management options, trapping, toxicants, and exclusion are likely more effective than repellents and habitat modification. However, no method is 100% effective.

For this project, exclusion through the use of rigid plastic tree protectors was deemed the most practical to implement and the most acceptable to the public. Smooth, solid plastic tree tubes with no external fasteners should be used in order to minimize the ability of the mountain beaver to climb or chew through the material. Tubes should be a minimum of 24 inches tall in order to prevent beavers from reaching the stem or lower branches of the tree. Tube diameter should be a minimum of 5-6 inches wide in order to give seedlings sufficient room to branch out. Tubes should be secured with 2-3 stakes inserted *within* the tube in order to prevent beaver from chewing through the stake or climbing up it. Tubes should be left around base of tree until tree stem reaches a minimum of 1.5 inches in diameter.

Unstable and Landslide-prone Slopes

Research on the relationships between forests and landslides indicates tree roots reduce the risk of hydrogeomorphic hazards (Sakals et al. 2006). Extreme rainfall has the greatest effect on soil slides because soil moisture is inversely related to soil cohesion and plasticity, and the forces created by surface and subsurface flow from extraordinary rainfall contributes to soil movement (Wu and Chen 2009). In shallow soils (<3 foot depth), soil cohesion is enhanced by roots forming vertical anchors and dense lateral networks (Johnson and Wilcock 2002). Also, trees modify the soil moisture regime through increased evapotranspiration (Greenway 1987), and species with deeper roots sustain higher transpiration for longer periods than shallowly rooted species (McNaughton and Jarvis 1983).

The Washington Department of Natural Resources defines potentially unstable slopes as having greater than 70 percent (35^{o}) slope (WADNR 2004). Additionally, *hollows,* which are present in places along the slopes of both Carkeek Park and the West Duwamish Greenbelt, present potentially unstable areas. Hollows are commonly spoon-shaped areas of convergent topography with concave profiles on hillslopes. They tend to be oriented linear upland down-slope. Their upper ends can extend to the ridge or begin as much as several hundred feet below ridge line. Most hollows are approximately 75 to 200 feet wide at their apex (but they can also be as narrow as several feet across at the top), and narrow to 30 to 60 feet downhill.

A study of colluvium covered slopes in the Cincinnati, Ohio, U.S., area showed that saplings with tap root systems could stabilize soil as thick as three feet, while saplings with a lateral root system could not stabilize soil thicker than 1.5 feet (Riestenberg 1994). Because tap root trees produce more depth in the root cohesion network, tap root trees should be preferred for planting to ameliorate the risk of soil slides (Riestenberg 1994). The following native Northwest tree species either produce tap roots or have deep rooting systems and are suggested for planting on areas where soil instability is known or suspected:

Table 2: Trees with taproots or deep rooting systems

Common name	Botanical name
Grand fir	Abies grandis
Big leaf maple	Acer macrophyllum
Pacific Madrone	Arbutus menziesii
Cascara	Cascara sagrada
Blue elderberry	Sambucus caerulea
Serviceberry	Amelanchier alnifolia

Minimizing landslide risk

The following strategies are recommended for minimizing the risk of landslide on areas where slope instability is known or suspected:

1. Retain all existing tree and shrub cover (with the exception of non-native invasive species),
2. Do not thin dominant or understory trees within a minimum of 50 feet surrounding a slide-prone area,
3. Site prep and underplant site as per recommendations above with the species listed in the table above. Plant at 200 stems per acre with Grand fir, maple and Madrone comprising, in equal proportions, 50 percent of the planting stock.
4. Maintain planted trees as per recommendations above.

Prescription 1: No cut, understory treatment

This prescription represents the least invasive and lowest cost strategy for establishing and maintaining conifers in the understory. The prescription solely focuses on treating competing understory vegetation to the extent necessary to alleviate its shade effects on tree seedlings.

Table 3: West Duwamish Greenbelt

Treatment	Description	Unit Cost	Total Cost
Site prep planting sites for 300 tpa.	Evenly distribute planting sites throughout area (12’x12’). No conifer planting site should be located closer than 10’ from an existing dominant or co-dominant tree. Prep planting sites as per recommendation in “Planting conifers and hardwoods” earlier in this document.	$1,526/acre	$12,208
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 2,400 seedlings total (1,600 conifer, 800 hardwood). All conifer seedling stock will be a minimum of P-1 (min. 12” height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of 2-3’ tall. Place fertilizer packet in planting hole prior to planting.	$0.54/conifer seedling	$864
		$0.90/conifer planting	$1,440
		$1.62/hardwood seedling	$1,296
		$2.15/hardwood planting	$1,720
		$0.16/fertilizer	$384
Year 1 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
		Total Project Budget	**$53,912**

Table 4: Carkeek Park

Treatment	Description	Unit Cost	Total Cost
Site prep planting sites for 300 tpa.	Evenly distribute planting sites throughout area (12’x12’). No conifer planting site should be located closer than 10’ from an existing dominant or co-dominant tree. Prep planting sites as per recommendation in “Planting conifers and hardwoods” earlier in this document.	$1,526/acre	$23,653
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 4,650 seedlings total (3,100 conifers, 1,550 hardwoods). All conifer seedling stock will be a minimum of P-1 (min. 12” height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of 2-3’ tall. Place fertilizer packet in planting hole prior to planting.	$0.54/conifer seedling	$1,674
		$0.90/conifer planting	$2,790
		$1.62/hardwood seedling	$2,511
		$2.15/hardwood planting	$3321
		$0.16/fertilizer	$744
Tube seedlings	Install 24” rigid plastic tree tube around all seedlings. Use2 stakes within tube to provide support. Do not use zip ties or other external support systems in order to keep outside surface of tube smooth.	$3.00/tube & stakes	$13,950
Year 1 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
		Total Project Budget	**$118,393**

Prescription 2: 30% thin, understory treatment

This prescription involves thinning and girdling 30% of the dominant and co-dominant alder, and co-dominant and suppressed maple across the entirety of the project sites, with the exception of the pre-existing low-stocked areas. Thinning and girdling will be carried out as described in the Canopy Transparency section above. Competing understory vegetation will be treated as per Prescription 1.

West Duwamish Greenbelt

Approximately two acres of this site are either in gaps or have areas of low-stocking that do not require further thinning to achieve the desired canopy transparency. Given the exposure along the east side of this project site, no treatment is proposed within the first 100 feet of the eastern park boundary, as light penetration into the stand should be sufficient to support understory conifer regeneration.

Figure 23: Pre-existing gaps and low-stocked areas. Green = gap, yellow = low-stocking.

Given the predominance of maple throughout this site as compared to Carkeek Park, maple will be targeted for thinning to a stand-wide density of five maples per acre, retaining the largest and most dominant trees. Smaller clumps of dense maple, such as the one occurring near Plot 9, will be retained as thinning these clumps will result in excessive biomass accretion to the forest floor.

Table 5: West Duwamish Greenbelt

Treatment	Description	Unit Cost	Total Cost
Thin 30% of stand	Fell or girdle 30% of hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above. Treat a net total of 4.5 acres (excluding low-stocked sites and 100' zone along eastern park boundary).	$750/acre	$3,375
Site prep planting sites for 300 tpa.	Evenly distribute planting sites throughout area (12'x12'). No conifer planting site should be located closer than 10' from an existing dominant or co-dominant tree. Prep planting sites as per recommendation in "Planting conifers and hardwoods" earlier in this document.	$1,526/acre	$12,208
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 2,400 seedlings total (1,600 conifer, 800 hardwood). All conifer seedling stock will be a minimum of P-1 (min. 12" height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of 2-3' tall. Place fertilizer packet in	$0.54/conifer seedling	$864
		$0.90/conifer planting	$1,440
		$1.62/hardwood seedling	$1,296

	planting hole prior to planting.	$2.15/hardwood planting	$1,720
		$0.16/fertilizer	$384
Year 1 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
		Total	**$57,287**

Carkeek Park

Approximately 4.5 acres of the project site are in pre-existing gaps or have low enough stocking to not require additional thinning to achieve the desired canopy transparency.

Figure 24: Pre-existing gaps and low-stocked areas. Green = gap, yellow = low-stocking.

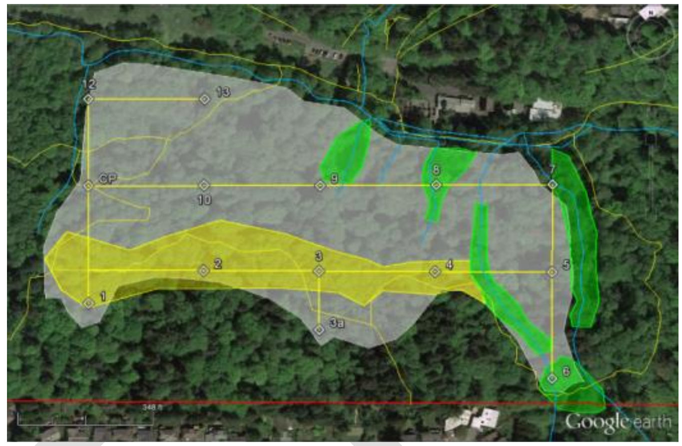


Table 6: Carkeek Park

Treatment	Description	Unit Cost	Total Cost
Thin 30% of stand	Fell or girdle 30% of hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above. Treat a net total of 10.1 acres (excluding gaps and low-stocked area).	$750/acre	$7,575
Site prep planting sites for 300 tpa.	Evenly distribute planting sites throughout area (12'x12'). No conifer planting site should be located closer than 10' from an existing dominant or co-dominant tree. Prep planting sites as per recommendation in "Planting conifers and hardwoods" earlier in this document.	$1,526/acre	$23,653
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 4,650 seedlings total (3,100 conifers, 1,550 hardwoods). All conifer seedling stock will be a minimum of P-1 (min. 12" height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of 2-3' tall. Place fertilizer packet in planting hole prior to planting.	$0.54/conifer seedling	$1,674
		$0.90/conifer planting	$2,790
		$1.62/hardwood seedling	$2,511
		$2.15/hardwood planting	$3321
		$0.16/fertilizer	$744
Tube seedlings Year 1 Competing Vegetation Control	Install 24" rigid plastic tree tube around all seedlings. Use2 stakes within tube to provide support. Do not use zip ties or other external support systems in order to keep outside surface of tube smooth. Cut back or spray competing vegetation as per recommendations in "Conifer Establishment Strategies" earlier in this document.	$3.00/tube & stakes	$13,950
		$900/acre	$13,950

Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in "Conifer Establishment Strategies" earlier in this document.	$900/acre	$13,950
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in "Conifer Establishment Strategies" earlier in this document.	$900/acre	$13,950
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in "Conifer Establishment Strategies" earlier in this document.	$900/acre	$13,950
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in "Conifer Establishment Strategies" earlier in this document.	$900/acre	$13,950
		Total Project Budget	**$125,968**

Prescription 3: 30% thin, gap creation/enhancement, understory treatment

This prescription involves expanding existing gaps to a minimum of 0.5 acres, creating additional gaps within lower stocked areas of the stand, and thinning 30 percent of the dominant and co-dominant hardwoods throughout the remainder of each site.

West Duwamish Greenbelt

Stand alteration at the West Duwamish Greenbelt will involve creating two 0.5 acre gaps in currently understocked areas of the stand, expanding a third pre-existing gap to 0.5 acres, and thinning 30 percent of the dominant and co-dominant hardwoods across the remainder of the site.

Given the exposure along the east side of this project site, no treatment is proposed within the first 100 feet of the eastern park boundary, as light penetration into the stand should be sufficient to support understory conifer regeneration.

Given the predominance of maple throughout this site as compared to Carkeek Park, maple will be targeted for thinning to a stand-wide density of five maples per acre, retaining the largest and most dominant trees. Smaller clumps of dense maple, such as the one occurring near Plot 9, will be retained as thinning these clumps will result in excessive biomass accretion to the forest floor.

Figure25: West Duwamish Greenbelt pre- and post-treatment. Green = existing gaps, yellow = lighter stocked areas, orange = new gaps.

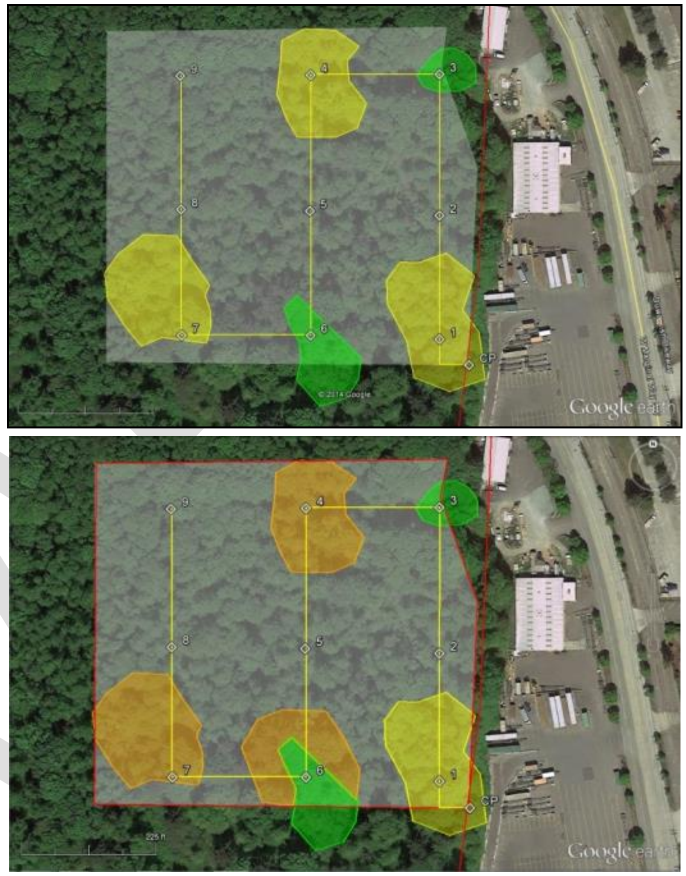


Table 7: West Duwamish Greenbelt

Treatment	Description	Unit Cost	Total Cost
Create 3 0.5-acre gaps	Cut and drop all hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above.	$1,500/acre	$2,250
Thin 30% of remaining stand	Cut and drop 30% of hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above. Treat a net total of 5 acres (excluding gaps and 100' zone along eastern park boundary).	$750/acre	$3,750
Site prep planting sites for 300 tpa.	Evenly distribute planting sites throughout area (12'x12'). No conifer planting site should be located	$1,526/acre	$12,208

	closer than 10’ from an existing dominant or co-dominant tree. Prep planting sites as per recommendation in “Planting conifers and hardwoods” earlier in this document.		
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 2,400 seedlings total (1,600 conifer, 800 hardwood). All conifer seedling stock will be a minimum of P-1 (min. 12” height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of 2-3’ tall. Place fertilizer packet in planting hole prior to planting.	$0.54/conifer seedling	$864
		$0.90/conifer planting	$1,440
		$1.62/hardwood seedling	$1,296
		$2.15/hardwood planting	$1,720
		$0.16/fertilizer	$384
Year 1 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$7,200
		Total	**$59,912**

Carkeek Park

Stand alteration at Carkeek Park will involve expanding some existing gaps to 0.5 acres, creating new gaps of 0.5 acres in size and thinning 30 percent of the dominant and co-dominant hardwoods across the remaining site. Currently approximately 1.5 acres of the project site is in open gaps and approximately 3 acres have lighter canopy cover than the majority of the site. The low-stocked area will not require additional thinning.

Given the high public use of this site, and the network of hiking trails, gaps will be primarily located downslope from trails in order to minimize public risk of additional windthrow in the stand resulting from gap creation. Gaps will generally be created on an east-west axis in order to optimize sunlight penetration into the gap, as well as into the stand along the northern edge of the gap to further support conifer regeneration in the understory.

Figure26: Carkeek Park pre- and post-treatment. Green = existing gaps, yellow = lighter stocked areas, orange = new gaps.

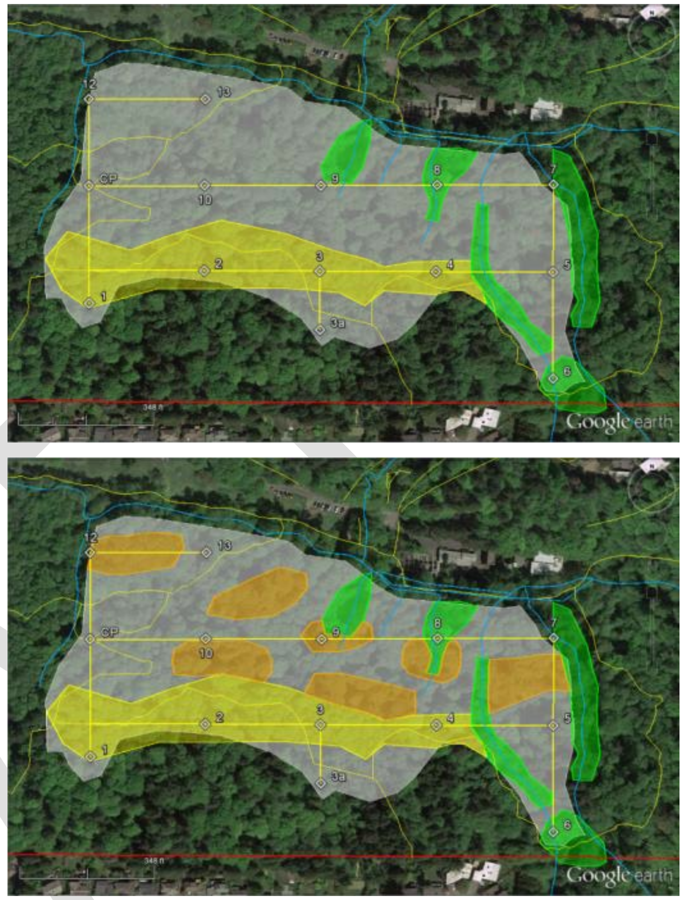


Table 8: Carkeek Park

Treatment	Description	Unit Cost	Total Cost
Create 5 0.5 acres gaps, and expand two existing gaps by 0.25 acres.	Cut and drop all hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above.	$1,500/acre	$4,500
Thin 30% of remaining stand	Fell and girdle 30% of hardwoods and mitigate slash within gaps as per the recommendations detailed in the Canopy Transparency section above. Treat a net total of 7.1 acres (excluding gaps and low-stocked area).	$750/acre	$5,325
Plant tree seedlings	Plant 300 tpa using bareroot planting stock. 4,650 seedlings total (3,100 conifers, 1,550 hardwoods). All conifer seedling stock will be a minimum of P-1 (min. 12” height) and from a seed source suited to the site. Hardwood tree and shrub stock should be a minimum of	$0.54/conifer seedling	$1,674

	2-3’ tall. Place fertilizer packet in planting hole prior to planting.		
Tube seedlings Year 1 Competing Vegetation Control	Install 24” rigid plastic tree tube around all seedlings. Use2 stakes within tube to provide support. Do not use zip ties or other external support systems in order to keep outside surface of tube smooth. Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$0.90/conifer planting	$2,790
		$1.62/hardwood seedling	$2,511
		$2.15/hardwood planting	$3321
		$0.16/fertilizer	$744
		$3.00/tube & stakes	$13,950
Year 2 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
		$900/acre	$13,950
Year 3 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 4 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
Year 5 Competing Vegetation Control	Cut back or spray competing vegetation as per recommendations in “Conifer Establishment Strategies” earlier in this document.	$900/acre	$13,950
		Total Project Budget	**$104,565**

Prescription 4 (West Duwamish Greenbelt): Commercially thin alder & maple, gap creation/enhancement, understory treatment.

This prescription focuses solely on the project site at the West Duwamish Greenbelt. The prescription mirrors Prescription 3 above, but calls for the commercial extraction of merchantable alder and maple logs. It is assumed that access to the site for log trucks can be made either at the northeast corner, or along the eastern park boundary.

Under this prescription, only merchantable quality alder and maple trees (minimum 12” dbh) will be removed.

Table 9: Harvest cost/revenue for West Duwamish Greenbelt forest restoration.

Harvest area	RA Harvest Volume	BM Harvest Volume	$/MBF	Gross Harvest Value	Logging Costs* (50%)	Net Revenue
5-acres thinned by 30%	15 MBF	20 MBF	$500/MBF	$17,500	$8,750	$8,750
1.5 acres of canopy gaps	13.5 MBF	20.5 MBF	$500/MBF	$18,500	$9,250	$9,250
					Revenue Subtotal	$18,000
					Restoration costs for Prescription 3**	$53,912
					Restoration Subtotal	$35,912

*includes logging, hauling, permitting. Does not include private consultants fees or road building.

**excluding felling and girdling costs

Appendix I. Hardwood Trees and Shrubs for Understory Planting

Standard Name	Common Name	Type
Acer macrophyllum	bigleaf maple	Trees
Arbutus menziesii	Pacific madrone	Trees
Cornus nuttallii	Pacific dogwood	Trees
Frangula purshiana	cascara	Trees
Malus fusca	western crabapple	Trees
Prunus emarginata var mollis	bitter cherry	Trees
Salix scouleriana	Scouler's willow	Trees
Acer circinatum	vine maple	Shrubs and Dwarf-shrubs
Amelanchier alnifolia	serviceberry	Shrubs and Dwarf-shrubs
Cornus unalaschkensis	western bunchberry	Shrubs and Dwarf-shrubs
Corylus cornuta var californica	beaked hazelnut	Shrubs and Dwarf-shrubs
Gaultheria shallon	salal	Shrubs and Dwarf-shrubs
Holodiscus discolor	oceanspray	Shrubs and Dwarf-shrubs
Lonicera ciliosa	orange honeysuckle	Shrubs and Dwarf-shrubs
Lonicera hispidula	hairy honeysuckle	Shrubs and Dwarf-shrubs
Lonicera involucrata var involucrata	black twinberry	Shrubs and Dwarf-shrubs
Mahonia aquifolium	tall Oregongrape	Shrubs and Dwarf-shrubs
Mahonia nervosa	dwarf Oregongrape	Shrubs and Dwarf-shrubs
Oemleria cerasiformis	Indian plum	Shrubs and Dwarf-shrubs
Oplopanax horridus	devil's club	Shrubs and Dwarf-shrubs
Philadelphus lewisii	mockorange	Shrubs and Dwarf-shrubs
Rhododendron macrophyllum	Pacific rhododendron	Shrubs and Dwarf-shrubs
Ribes bracteosum	stink currant	Shrubs and Dwarf-shrubs
Ribes divaricatum var divaricatum	coast black gooseberry	Shrubs and Dwarf-shrubs
Ribes lacustre	swamp currant	Shrubs and Dwarf-shrubs
Ribes sanguineum var sanguineum	red-flowering currant	Shrubs and Dwarf-shrubs
Rosa gymnocarpa	baldhip rose	Shrubs and Dwarf-shrubs
Rosa nutkana	nootka rose	Shrubs and Dwarf-shrubs
Rubus laciniatus	evergreen blackberry	Shrubs and Dwarf-shrubs
Rubus leucodermis	blackcap	Shrubs and Dwarf-shrubs
Rubus nivalis	snow bramble	Shrubs and Dwarf-shrubs
Rubus parviflorus var parviflorus	thimbleberry	Shrubs and Dwarf-shrubs
Rubus spectabilis var spectabilis	salmonberry	Shrubs and Dwarf-shrubs
Rubus ursinus ssp macropetalus	trailing blackberry	Shrubs and Dwarf-shrubs
Sambucus nigra ssp caerulea	blue elderberry	Shrubs and Dwarf-shrubs
Sambucus racemosa var racemosa	red elderberry	Shrubs and Dwarf-shrubs
Sorbus aucuparia	European mountain-ash	Shrubs and Dwarf-shrubs
Spiraea betulifolia var lucida	birch-leaf spirea	Shrubs and Dwarf-shrubs
Symphoricarpos albus var laevigatus	common snowberry	Shrubs and Dwarf-shrubs
Symphoricarpos hesperius	spreading snowberry	Shrubs and Dwarf-shrubs
Vaccinium ovatum	evergreen huckleberry	Shrubs and Dwarf-shrubs
Vaccinium parvifolium	red huckleberry	Shrubs and Dwarf-shrubs

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