

Postfire Response of Red Alder, Black Cottonwood, and Bigleaf Maple to the Whatcom Creek Fire, Bellingham, Washington.

Abstract

The June 1999 pipeline leak and subsequent explosion in Whatcom Creek resulted in a fire that scorched ~10 ha of conifer and riparian forest in Bellingham, Washington. This fire provided an opportunity to study the postfire responses of red alder, black cottonwood, and bigleaf maple in the 3.2-ha scorched riparian zone. Bigleaf maple endures all but the most intense fires, resprouting vigorously after fire. Red alder and black cottonwood are known resprouters that may survive low intensity fires, but data about their responses to fire are sparse. The postfire status of every tree in the burn zone was evaluated immediately after the fire in June 1999, and during the first postfire growing season in May 2000. Tree response, in relation to trunk diameter, percent crown scorch, and percent bark scorch, was categorized as 1) alive with a new leafy crown; 2) topkilled and resprouted; or 3) dead. Fire intensity was higher on the left bank (left side of the creek when facing downstream), where trees experienced greater mortality. More than half the 854 trees in the burn zone survived the fire, 57% by forming new leafy crowns and 43% by resprouting. Red alder, black cottonwood, and bigleaf maple demonstrated abilities to survive a disturbance to which they are not ordinarily subjected. All three species resisted low intensity fire and reformed leafy crowns on the right bank, and they endured moderate to high intensity fire by resprouting after topkill on the left bank. On the left bank, probabilities of surviving 100% crown scorch were 0.24 for red alder, 0.66 for black cottonwood, and 0.68 for bigleaf maple; probabilities of surviving 100% bark scorch were 0.09 for red alder, 0.66 for black cottonwood, and 0.60 for bigleaf maple.

Introduction

On 10 June 1999, an underground fuel pipeline in Bellingham, Washington, ruptured and spilled ~866,000 liters of gasoline. The majority of this fuel leaked into Hannah Creek, from there to Whatcom Creek (Figure 1), eventually reaching salt water at Bellingham Bay ~3.5 km west of the spill. By mid-afternoon, Whatcom Creek was essentially an aqueous mixture of gasoline, with heavy gasoline vapors hanging over the creek. At 5:02 PM, the fuel ignited, sending a rolling fire ball along Whatcom Creek. Fortunately, a small spillway associated with a pipeline crossing Whatcom Creek at Pacific Street disrupted fuel continuity, stopping the fire before it could travel west of the Interstate-5 freeway into downtown Bellingham (Figure 1).

Behavior of this fire differed from a wildland fire. Fuel was supplied by gasoline in the creek rather than forest litter, and the fire was a brief explosion rather than being sustained for some period of time in the forest (Table 1). Spring 1999 was quite wet in western Washington, so that woody and nonwoody fuels were wet at the time of the fire. Consequently, the fireline remained stationary in the creek, and the fire went out when the gasoline was exhausted. Many times creeks act as fuel breaks, so that wildland fires burn on one

bank. For this fire, however, Whatcom Creek was the source of the flames, and trees on both banks were in the fire zone (Table 1). Rather than causing the fireline to advance steadily through the forest stand, winds from the north directed the flames southward to the left bank. The Whatcom Creek incident ended in about 15 min, whereas wildland fires often last many times longer. Wildland firelines move, so that fire remains briefly at any one point in the stand. Eventually every spot gets burned by essentially the same fire intensity (low, moderate, or high). At Whatcom Creek, fire was constant along the creek banks for the duration of the fire. On the left bank, trees adjacent to the creek experienced high intensity fire, whereas those 20 m away experienced lower intensity fire. The result of this differential variability was that most of the dead trees occupied sites close to the creek.

The fire damaged major components of the aquatic ecosystem, but terrestrially it affected only trees and understory plants, which were scorched by flame and heat. I interviewed eye witnesses who were at the SW corner of Valencia Street and Whatcom Creek (Figure 1), and Bellingham Fire Department personnel about flame heights and times. The times given below are estimates; these events were not timed by observers. The

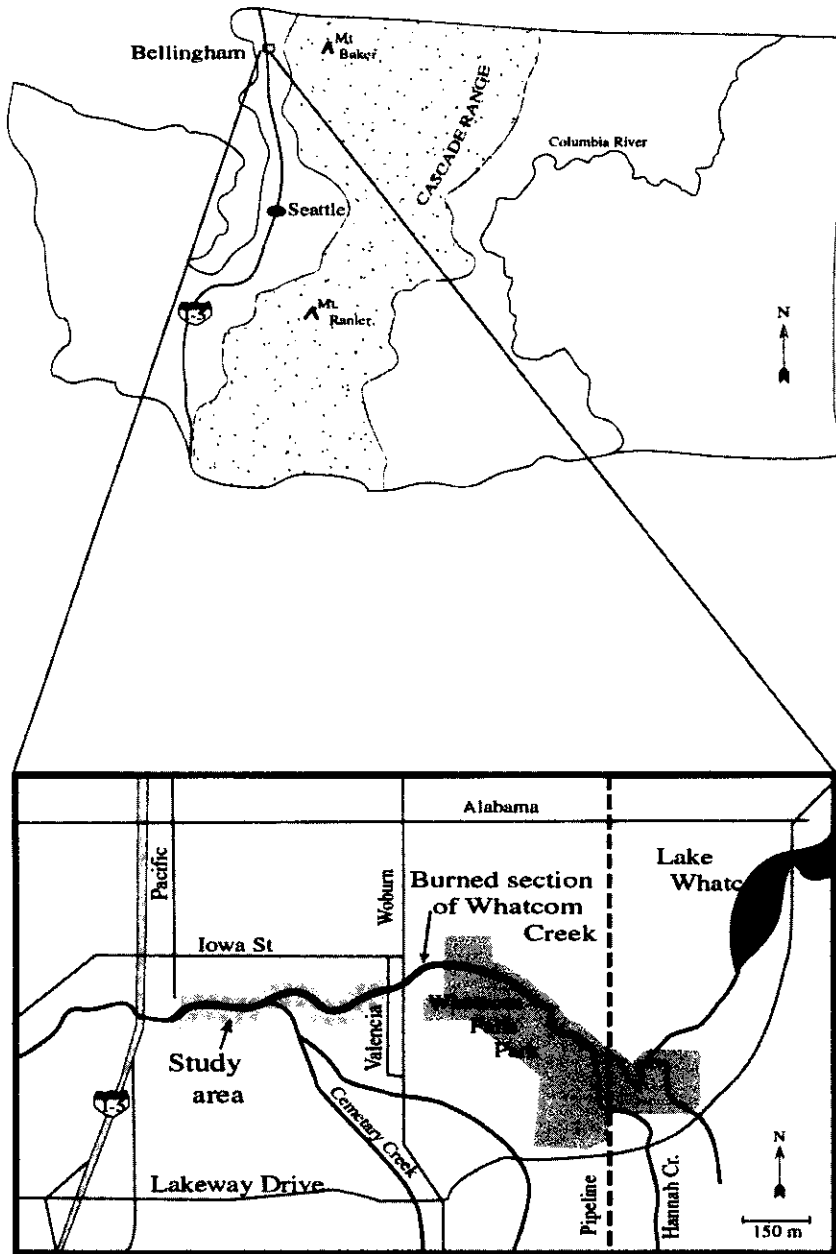


Figure 1. The burn zone extended from Whatcom Falls Park west to Pacific Street, indicated by a heavier line for that portion of Whatcom Creek. The study area extended from Valencia Street to Pacific Street.

initial explosion sent flames higher than black cottonwoods (*Populus trichocarpa*) 38-45 m tall bordering the creek at Valencia Street (Figures 2, 3), for perhaps 3 min maximum. Fire personnel

closer to Whatcom Falls Park estimated flame heights at ~45 m, again for short duration. Subsequently, at Valencia Street, flames were sustained clearly below the level of the tallest trees. Flames

TABLE 1. Qualitative comparison of a lightning-ignited wildland fire in a forest stand with the Whatcom Creek fire.

Attribute	Wildland fire	Whatcom Creek fire
Fuel	Dead organic matter	Gasoline
Fire behavior	Sustained burning	Explosion
Fire weather	Usually hot, dry	Mild, moist
Role of wind	Advances the fireline	Directed flames to left bank
Fireline	Advances through the stand	Stationary
Role of creek	Fuel break; often prevents fire on the opposite bank	Source of the fire; allowed fire on both banks
Flame length	Shorter	Longer
Duration of fire		
—entire incident	Longer	Shorter
—at one point	Shorter	Longer
Fire intensity variability across the burn zone	Low	High



Figure 2. Upstream view of the burned riparian community along Whatcom Creek, July 1999. Fire severity was greater on the left bank (right side of photo), as indicated by high crown scorch volumes, heavy bark scorch, and burned understory. The large trees on the banks are black cottonwoods; initial flame heights cleared the tops of these trees. The smaller trees along the water on the left bank are dead red alders.



Figure 3. Same view of riparian vegetation in June 2000. Leafy crowns have returned to trees on the right bank (left side of photo), and to some of the large cottonwoods on the left bank. The two large cottonwoods in the left bank foreground have produced root sprouts. The char collars visible on these large trees are 11-15 m high. Snowberry is the most abundant species in the understory in the right foreground.

pulsed up and down as the fire rolled along the creek. Total flame time was ~10-15 min, except for small pockets of gasoline pooled in the creek, which continued to burn with flames <1 m long for some time after the main fire was extinguished. Char collars on the trunks of the cottonwoods in Figures 2 and 3 ranged from 11 to 15 m on the sides facing the creek, and 1-2 m higher on the lee side, which I interpret as the sustained heights of the flames as the gasoline was consumed. This height was below the tops of most red alders (*Alnus rubra*) and bigleaf maples (*Acer macrophyllum*) in this area, the tallest of which are ~32 m tall. A plume of black smoke rose an estimated 10 km over the burn zone, which the north wind carried to the south. Most of the heat and flames were directed upward by the banks of the creek (Figure 2), so that trees a few meters or more behind the creek bank had merely light scorching in the lower 1-2 m of the trunk. Except for the soil on the banks adjacent to Whatcom Creek, little soil was burned by the fire and heat could not have penetrated far. I noted many weedy seeds germinated in the burned zone within a few weeks of the fire, which provides anecdotal evidence to confirm low soil temperatures.

About 10 ha of forest was scorched in the entire burn zone. The eastern portion of the burn zone lies in Whatcom Falls Park (Figure 1), the site of the fuel spill, where the creek is incised in a deep canyon. The surrounding forest is dominated by second-growth Douglas-fir (*Pseudotsuga menziesii*), western redcedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*). Whatcom Creek exits this canyon and enters the floodway zone west of Woburn Street (Figure 1), where the creek was channelized before 1940 for flood control through the main portion of Bellingham. Between Valencia Street and Pacific Street (Figure 1), the creek was bordered at the time of the fire by a typical low-elevation riparian community dominated by red alder, black cottonwood, and bigleaf maple. Based on the distribution of all trees with scorched crowns, maximum width of the burn zone west of Valencia Street was 35 m and total area was 3.2 ha.

This paper examines three deciduous species found in lowland riparian zones. Red alder is a fire invader (Agee 1993). Invaders usually are not members of fire-prone communities, but they benefit from the disturbance to regenerate on the postfire site via seeds. The thin bark is sufficient

to protect against light surface fire, but flammability of the foliage and leaf litter is low (USDA Forest Service 1998). Stands of trees dominated by red alder survived low intensity burns associated with fires in 1939 and 1945 at Tillamook, Oregon (Bailey and Poulton 1968). No other information is available on the postfire response of red alder. Several references describe the ability of red alder to sprout epicormically (Berntsen 1961, Fowells 1965, Harrington 1984, USDA Forest Service 1998). Harrington (1984) provided extensive information on the ability of red alder in western Washington to sprout or coppice after cutting. Red alder is not considered a vigorous sprouter, but cut trees are able to regenerate stem sprouts from suppressed buds near the root collar or on the lower 10-15 cm of the stem. This characteristic is important for the Whatcom Creek fire, because the combination of flames directed upward by creek banks and wet litter resulted in lower fire severity near ground level. Trees younger than 10 yr are more likely to sprout than older trees, and trees cut between April and August have the lowest probability of survival (Harrington 1984). The Whatcom Creek fire burned in the middle of this time frame.

Black cottonwood is a fire invader (Agee 1993). Mature trees may survive low and moderate intensity fires, but trees of any age are killed by high intensity fires (USDA Forest Service 1998). In general, the relatively thin bark of younger trees, and the shallow root systems, makes black cottonwood susceptible to fire damage (Fowells 1965). The thicker bark of older, larger trees may afford some fire protection. Black cottonwood is a known sprouter from root crowns and from root suckers (Fowells 1965, Braatne et al. 1996), and top-killed trees may produce epicormic sprouts (USDA Forest Service 1998). There are no reports that black cottonwood produces root sprouts in response to fire (USDA Forest Service 1998).

Bigleaf maple is a fire endurer (Agee 1993). The ability to resprout from stem, root crown, or roots after top-kill by fire is an important adaptation, and species with this ability are termed endurers. Top-killed bigleaf maple trees can resprout from root crowns after fires (USDA Forest Service 1998). Riparian stands dominated by bigleaf maple survived low intensity fires in 1939 and 1945 at Tillamook, Oregon (Bailey and Poulton 1968). One year after slash-burning treatments in the western Cascades, Oregon, bigleaf maple

frequency was unchanged (Dyrness 1973). If roots survive fire, bigleaf maple can tolerate all but the most intense fires, because it resprouts vigorously from root crowns (Fowells 1965, Haeussler and Coates 1986, USDA Forest Service 1998).

The most detailed study on postfire resprouting of hardwood trees was conducted on turkey oak (*Quercus laevis*) in Florida (Rebertus et al. 1989). Percentage top-kill was a strong indicator of resprouting success for turkey oak. The probability of postfire survival was higher when most or all of the plant was top-killed. The total loss of apical dominance stimulated the plants to concentrate the energy reserves to form the new crown. In contrast, partially top-killed turkey oaks attempted to reform what was left of the canopy, thereby allocating little energy to developing buds in the root crown. Many of these partially top-killed plants died in subsequent years. Valley oak (*Q. lobata*) in California demonstrated similar resprouting abilities after top-kill by crown fire or severe ground fire (Griffin 1980). In the first postfire year, well over half the top-killed oaks had produced sprouts. Similar postfire responses have been described for other oak species in California (Plumb 1980, Haggerty 1994). Agee (1993) suggested that birches (*Betula* spp.), madrone (*Arbutus menziesii*), and tanoak (*Lithocarpus densiflora*) are capable of basal resprouting when the crowns are severely injured or killed.

The Whatcom Creek fire provided an opportunity to assess postfire responses of red alder, black cottonwood, and bigleaf maple, species that ordinarily are not subjected to wildfires. The objectives of the study were 1) to document postfire responses of these three species as related to resistance, top-kill and resprouting ability, and mortality, and 2) to provide estimates of survival probabilities for each species.

Methods

I evaluated the postfire status of every tree in the burn zone between Valencia and Pacific Streets (Figure 1) in June 1999 and again in May 2000. The immediate postfire effects were tallied 23-24 June 1999, when tree status was judged as alive, dead, or unknown. Trees with unknown status accounted for 25% of all trees surveyed in 1999. I estimated trunk diameter of each tree by diameter class (<10 cm, 10-30 cm, 31-60 cm, 61-90 cm, and >90 cm), crown scorch volume to the nearest 5%, and percent bark scorch to the near-

est 5%. Crown scorch volume (CSV) is percent of the three-dimensional crown scorched by the fire (Peterson 1985, Agee 1993), and is considered a better estimator of fire severity than scorch height. Percent bark scorch also was estimated on a three-dimensional basis, using all sides of the trunk and main branches. Data on the postfire categories were grouped by left bank and right bank responses, because fire intensity differed on opposite sides of the creek. When one faces downstream, the left bank of the creek is on the left, the right bank is on the right. This terminology describes location more accurately than compass direction, because creeks meander through all compass bearings. Prevailing winds directed the flames and heat toward the left bank of the creek, and away from the right bank, leading to higher fire severity on the left bank. Although some trees had begun to resprout by August 1999, and intact canopies still existed on trees judged alive in June, postfire condition was not evaluated again until 16 May 2000. At that time, I completely reevaluated every tree in the burn zone, and categorized each as 1) alive with a new leafy crown; 2) top-killed but resprouted by stem sprouts, root crown sprouts, or root sprouts; or 3) dead. The heights of trees and char collars were measured in spring 2000 with a Leiss BL7 altimeter. Postfire responses were summarized according to left/right bank, trunk diameter, CSV, and percent bark scorch. Values for CSV and bark scorch were analyzed by logistics regression (Wilkinson 1998), for each species according to left/right bank location, to determine probabilities of survival at 50% and 100% scorch.

Results

Total Tree Inventory

Before the fire, 514 red alders grew in the burn zone. After the fire, 66% were dead (Table 2). Of those alive one year after the fire, 45% had produced new leafy crowns. All of these alders grew on the right bank. For left bank alders, 76% died and none produced leafy crowns in spring 2000. A total of 96 alders (19%), top-killed by the fire, resprouted by May 2000. All but 10 were epicormic sprouts from the main trunk (Table 2).

Most of the 268 black cottonwoods in the burn zone survived the fire. Only 22% died, about evenly distributed between the left and right banks (Table 2). Over half of the 268 cottonwoods, most of

TABLE 2. Total tree inventory, in May 2000, in response to the Whatcom Creek fire. Leafy crown: trees were alive and had formed new leaves from buds established in summer 1999. Stem resprout: top-killed trees with branch sprouts from buds on the stem. Root resprout: top-killed trees with branching sprouts from root crowns or roots. Dead: no visible living tissues.

	Alive			Dead	Total
	Leafy crown	Stem resprout	Root resprout		
Red alder					
Left bank	0	70	10	254	334
Right bank	77	16	0	87	180
Total	77	86	10	341	514
Black cottonwood					
Left bank	17	17	31	28	93
Right bank	140	3	0	32	175
Total	157	20	31	60	268
Bigleaf maple					
Left bank	0	6	21	13	40
Right bank	18	14	0	0	32
Total	18	20	21	13	72
All species combined					
Left bank	17	93	62	295	467
Right bank	235	33	0	119	387
Total	252	126	62	414	854

them on the right bank, produced new leafy crowns in spring 2000 (Figure 3). About 19% of black cottonwoods were top-killed by the fire, but they resprouted from the stem, root crown, or roots. All but three of these resprouters were on the left bank. About 30% of black cottonwoods on the left bank died; 18% died on the right bank.

Fewer than 75 bigleaf maples grew in the burn zone, and 82% survived the fire (Table 2). All dead bigleaf maples were on the left bank, and none on the left bank survived unharmed. Over half of the 40 bigleaf maples on the left bank were top-killed, but most resprouted from root crowns (Figure 4). By contrast, all top-killed bigleaf maples on the right bank resprouted by stem sprouts. All bigleaf maples with leafy crowns in spring 2000 grew on the right bank (Table 2).

Over 850 trees were evaluated, of which 52% were alive in May 2000. Approximately 30% survived to form leafy crowns, of which 93% were on the right bank (Figure 3). A total of 188 top-killed trees resprouted by May 2000. The left bank, which bore the brunt of the fire, held ~80% of the resprouters. Many of the cottonwoods and maples had resprouted in 1999 within six weeks of the fire, but those data are not included in Table 2. Of the 414 dead trees, 82% were red alders.

Responses by Diameter Class

The most common diameter class in the burn zone was 10-30 cm, which accounted for 62% of the trees (Table 3). The 31-60 cm diameter class accounted for 27% of the trees. Trunk diameter was a less important factor in the response to fire than left/right bank location, however. For instance, red alders with leafy crowns were represented in three diameter classes, but only on the right bank. Conversely, resprouted alders occurred in three diameter classes, almost all on the left bank. Over half the <10 cm alders, and 69% of the 10-30 cm alders, perished in the fire.

Black cottonwoods with leafy crowns were distributed across all diameter classes, 89% of them on the right bank (Table 3). Before the fire, 14 black cottonwoods <10 cm diameter lived in the burn zone. Only five survived, three of which resprouted. Left bank resprouters were about evenly distributed in the three diameter classes from 10 to 90 cm diameter (Table 3). Cottonwoods >60 cm produced prolific sprouts from the roots, many of which were several meters from the main trunk. Most of the big cottonwoods survived the fire (Figures 2, 3). Only three cottonwoods > 60 cm diameter died in the fire (Table 3), and two of them leaned over the creek directly into the flames. The third grew on a peninsula where Cemetery



Figure 4. Top-killed bigleaf maple on the left bank, resprouting from the root crown. Dead red alders on the left bank are visible behind the maple. In the background are leafy crowns of black cottonwoods, bigleaf maples, and red alders on the right bank. Grasses in the foreground were killed by postfire herbicide applications associated with rehabilitation efforts.

Creek joined Whatcom Creek (Figure 1). Gasoline that had flowed into Cemetery Creek also ignited, so that this cottonwood was surrounded by flames, in contrast to all other cottonwoods in the burn zone.

The 18 bigleaf maples with leafy crowns were 10-60 cm diameter, and all were on the right bank (Table 3). Resprouting bigleaf maples were concentrated in the 10-30 cm diameter class, about evenly divided between left and right banks. The 13 dead bigleaf maples were 10-60 cm diameter.

Responses by Crown Scorch Volume

Scorched crowns on these deciduous trees were the most obvious postfire images along Whatcom Creek west of Valencia Street. The limits of the burn zone were defined in June 1999 to include

TABLE 3. Tree response to the Whatcom Creek fire, by diameter class, as of May 2000. Leafy crown: trees were alive and had formed new leaves from buds established in summer 1999. Resprout: top-killed trees with branch sprouts from buds on the stem, root crowns, or roots. Dead: no visible living tissues. No red alder or bigleaf maple exceeded 60 cm diameter.

	Diameter (cm)				
	< 10	10-30	31-60	61-90	>90
Leafy crown					
Red alder					
Left bank	0	0	0	-	-
Right bank	15	40	22	-	-
Black cottonwood					
Left bank	0	2	4	8	3
Right bank	2	46	79	12	1
Bigleaf maple					
Left bank	0	0	0	-	-
Right bank	0	8	10	-	-
Resprout					
Red alder					
Left bank	4	68	8	-	-
Right bank	0	9	7	-	-
Black cottonwood					
Left bank	1	19	17	10	1
Right bank	2	1	0	0	0
Bigleaf maple					
Left bank	5	17	5	-	-
Right bank	0	13	1	-	-
Dead					
Red alder					
Left bank	14	185	55	-	-
Right bank	11	73	3	-	-
Black cottonwood					
Left bank	2	17	6	3	0
Right bank	7	22	3	0	0
Bigleaf maple					
Left bank	0	6	7	-	-
Right bank	0	0	0	-	-

all trees with crown scorch, so that only 23 trees in the burn zone had 0% CSV. About 17% of the trees with $\geq 50\%$ CSV survived to form leafy crowns in spring 2000 (Table 4). More impressively, 26% of trees with $\geq 50\%$ CSV resprouted, 83% of them on the left bank. Still, all but three of the dead trees had $\geq 50\%$ CSV (Table 4). Red alder, black cottonwood, and bigleaf maple can survive 100% CSV, either to form leafy crowns the next growing season or to resprout. Of the 600 trees with 100% CSV, 34% survived to spring 2000. Of the survivors, 81% were resprouters. More

black cottonwoods and bigleaf maples with 100% CSV survived than died (Table 4).

Responses by Bark Scorch

Bark scorch was an important effect of the Whatcom Creek fire. Only 8 trees with leafy crowns in spring 2000 had $\geq 50\%$ bark scorch, whereas 341 dead trees had $\geq 50\%$ bark scorch (Table 5). Most of the trees that formed leafy crowns in spring 2000 had 0% bark scorch. Left bank resprouters responded well to $\geq 50\%$ bark scorch; about 74% of all left bank resprouters had $\geq 50\%$ bark scorch.

TABLE 4. Tree response to the Whatcom Creek fire, by crown scorch volume, as of May 2000. Leafy crown: trees were alive and had formed new leaves from buds established in summer 1999. Resprout: top-killed trees with branch sprouts from buds on the stem, root crowns, or roots. Dead: no visible living tissues.

	Crown scorch volume			
	0	5-45	50-95	100
Leafy crown				
Red alder				
Left bank	0	0	0	0
Right bank	9	28	19	21
Black cottonwood				
Left bank	1	4	10	2
Right bank	9	68	51	12
Bigleaf maple				
Left bank	0	0	0	0
Right bank	4	6	3	5
Resprout				
Red alder				
Left bank	0	1	7	72
Right bank	0	1	1	14
Black cottonwood				
Left bank	0	1	8	39
Right bank	0	0	2	1
Bigleaf maple				
Left bank	0	0	1	26
Right bank	0	0	0	14
Dead				
Red alder				
Left bank	0	0	7	247
Right bank	0	1	2	84
Black cottonwood				
Left bank	0	0	7	21
Right bank	0	2	1	29
Bigleaf maple				
Left bank	0	0	0	13
Right bank	0	0	0	0

No red alders on the left bank produced leafy crowns, regardless of percent bark scorch, although 77 alders on the right bank, 22 with 5-45% bark scorch, produced leafy crowns (Table 5). Resprouting and dead alders were found in every category of bark scorch, from 0% to 100% on both banks of the creek, with the majority on the left bank. Most of the resprouters were in the 50-95% class, whereas most of the dead alders were in the 100% class. Dead alders on the right bank were evenly distributed through the three bark scorch classes spanning 5-100%.

TABLE 5. Tree response to the Whatcom Creek fire, by percent bark scorch classes, as of May 2000. Leafy crown: trees were alive and had formed new leaves from buds established in summer 1999. Resprout: top-killed trees with branch sprouts from buds on the stem, root crowns, or roots. Dead: no visible living tissues.

	Percent bark scorch			
	0	5-45	50-95	100
Leafy crown				
Red alder				
Left bank	0	0	0	0
Right bank	53	22	2	0
Black cottonwood				
Left bank	4	7	6	0
Right bank	102	38	0	0
Bigleaf maple				
Left bank	0	0	0	0
Right bank	18	0	0	0
Resprout				
Red alder				
Left bank	21	8	33	18
Right bank	6	5	3	2
Black cottonwood				
Left bank	0	8	24	16
Right bank	0	0	2	1
Bigleaf maple				
Left bank	0	4	5	18
Right bank	7	5	2	0
Dead				
Red alder				
Left bank	2	5	58	189
Right bank	9	29	28	21
Black cottonwood				
Left bank	0	3	14	11
Right bank	13	12	6	1
Bigleaf maple				
Left bank	0	0	0	13
Right bank	0	0	0	0

Black cottonwoods with little bark scorch produced more leafy crowns in spring 2000 than red alder or bigleaf maple (Table 5). Most leafy crown cottonwoods were on the right bank. Left bank cottonwoods that survived $\geq 50\%$ bark scorch resprouted strongly. Mortality and resprouting of black cottonwoods related to left/right bank location and bark scorch. For example, most of the dead cottonwoods on the left bank sustained $\geq 50\%$ bark scorch, whereas most of the dead cottonwoods on the right bank sustained $< 50\%$ bark scorch. Many of the heavily scorched cottonwoods on the left bank resprouted.

All bigleaf maples with leafy crowns had 0% bark scorch, whereas all dead maples had 100% bark scorch (Table 5) and 100% CSV (Table 4). No left bank maples had 0% bark scorch, and no right bank maples had 100% bark scorch. Bigleaf maples resprouted across all four bark scorch classes. Left bank maples with 100% bark scorch accounted for 44% of all resprouted maples.

Discussion

Left/right bank location, tree diameter, crown scorch volume, and percent bark scorch were important determinants of postfire mortality and survivorship. Trees on the left bank suffered greatest mortality, primarily those < 60 cm dbh (Table 3), highest CSV (Table 4), and highest percent bark scorch (Table 5). Yet, 37% of the trees on the left bank survived the fire, mostly by resprouting (Table 2; Figure 4). Trees on the right bank fared better, where 69% survived the fire. Most of the right bank trees produced new leafy crowns in spring 2000 (Table 2; Figures 3, 4), indicating low severity fire. Figures 2 and 3 show the postfire responses immediately after the fire and one year later. Leafy crowns are prominent in both photos. The smaller trees are dead, but the two cottonwoods in the foreground on the right bank produced root sprouts in 2000. Snowberry (*Symphoricarpos albus*) in the understory resprouted strongly in 2000 (Figure 3).

The probabilities of survival differed among the three species, and reflected the different fire intensities on the two banks of Whatcom Creek (Table 6). Figure 5 shows probabilities of survival for crown-scorched alder and cottonwood on the left bank, as representatives of the models generated by logistics regression. Red alder had the lowest probability of survival on either bank, and clearly suffered the greatest losses in this fire

(Tables 2-5). Except for right bank trees with 50% CSV, the probability that red alder will survive with at least 50% CSV or 50% bark scorch was ≥ 0.52 (Table 6; Figure 5). The lowest survival probability was on the left bank for trees with 100% bark scorch. Black cottonwood survival probabilities generally were much higher than red alder, even with high percentages of CSV and bark scorch (Table 6; Figure 5). All values were ≥ 0.50 , except for right bank trees with either 50% or 100% bark scorch. There were few cottonwoods in these bark scorch categories, however, so that

TABLE 6. Probability of survival for each species at 50% and 100% CSV and bark scorch, according to left bank/right bank location. There were no dead bigleaf maples on the right bank.

	CSV		Bark scorch	
	50	100	50	100
Red alder				
Left bank	0.52	0.24	0.50	0.09
Right bank	0.97	0.33	0.42	0.29
Black cottonwood				
Left bank	0.92	0.66	0.78	0.66
Right bank	0.95	0.52	0.25	0.01
Bigleaf maple				
Left bank	0.62	0.68	1.00	0.60
Right bank	1.00	1.00	1.00	1.00

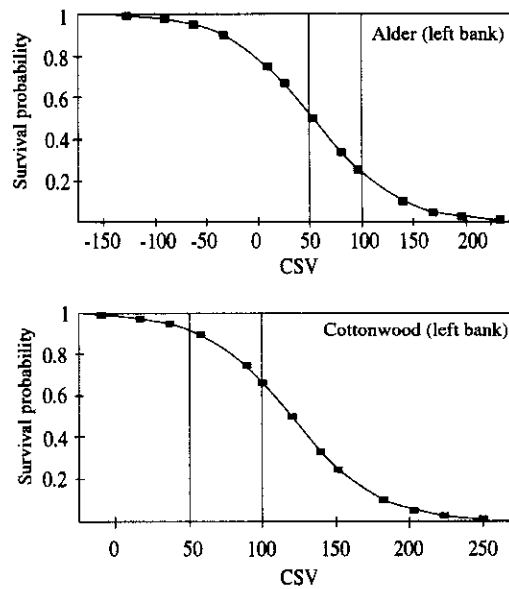


Figure 5. Models of survival probabilities of crown-scorched alder and cottonwood on the left bank of Whatcom Creek.

the values 0.25 and 0.01 may be unreliable. For example, only 9 cottonwoods on the right bank had $\geq 50\%$ bark scorch, of which two survived (Table 5). For cottonwood, high percent bark scorch contributed more strongly than high CSV to lower survival probabilities. Bigleaf maple is a known fire endurer, and these data confirm that classification. The probability that bigleaf maple will survive was ≥ 0.60 on the left bank (Table 6). The model predicts slightly higher probability of survival at 100% CSV than 50% CSV, because of the 39 maples with 100% CSV, 26 lived and only 13 died (Table 4). Because no maples died on the right bank, survival probabilities of 1.00 may be unreliable; conversely, they may accurately predict maple survival in low to moderate intensity fires.

These three species are known resprouters, from shoots and root crowns (Berntsen 1961, Fowells 1965, Harrington 1984, Haeussler and Coates 1986, USDA Forest Service 1998), and all are known to have survived low intensity fires in the past (Bailey and Poulton 1968, Dyrness 1973, USDA Forest Service 1998). Bigleaf maple is the only species of the three for which resprouting from root crowns has been documented in response to low intensity fire (Bailey and Poulton 1968, Haeussler and Coates 1986, USDA Forest Service 1998). Generally, red alder, black cottonwood, and bigleaf maple have been considered unable to resist or endure high intensity fires, such as experienced by the left bank of Whatcom Creek (Dyrness 1973, Agee 1993, USDA Forest Service 1998). It is clear from the postfire response to the Whatcom Creek incident, especially on the left bank, that these species endure at least moderate intensity fire, and they probably can endure high intensity fire. All species were represented on the left bank by trees that resprouted epicormically from stems and root crowns, and from the roots of large black cottonwoods in response to fire. The left/right bank responses provide insight into fire intensity/severity relationships. Fire intensity and fire severity clearly were higher on the left bank (Tables 2-5). The probabilities of surviving such a fire were correspondingly lower for all three species than the comparatively less intense right bank fire environment (Table 6).

Resprouting is an excellent adaptation to fire (Agee 1993), although resprouting ability evolved

primarily as an adaptation to herbivory (Lopez-Soria and Castell 1992). A few bitter cherries (*Prunus emarginata*), vine maples (*Acer circinatum*), and Scouler willows (*Salix scouleriana*) also survived the Whatcom Creek fire by resprouting, especially on the left bank. Moreover, snowberry, oceanspray (*Holodiscus discolor*), sword fern (*Polystichum munitum*), red elderberry (*Sambucus racemosa* var. *arborescens*), thimbleberry (*Rubus parviflorus*), Pacific blackberry (*R. ursinus*), and Himalayan blackberry (*R. discolor*) resprouted prolifically to provide abundant understory cover in the first postfire year (Figure 3). Although riparian ecosystems are seldom subjected to wildfire, prolific resprouting by many of the resident species has reestablished much of the community along Whatcom Creek.

Top-kill and resprouting are important responses to fire. Resprouting success of turkey oaks in Florida depended heavily on complete top-kill (Rebertus et al. 1989). Valley oaks in California successfully resprouted when 100% of the crown was killed. The Whatcom Creek data suggest that red alder, black cottonwood, and bigleaf maple responded similarly. Of the resprouted trees in the burn zone, 88% had 100% CSV (Table 4). This positive response by hardwoods to 100% CSV differs from the negative response by conifers, for which 100% CSV is a sure indicator of mortality (Wagner 1961, Methven 1971, Peterson 1983a, Peterson 1983b, Peterson and Arbaugh 1986, Ryan and Reinhardt 1988).

Fire resistance is an excellent adaptation in a fire prone environment in the Pacific Northwest (Agee 1993). Previously, bigleaf maple was characterized as an endurer; red alder and black cottonwood were characterized as invaders. Although riparian zones are not fire prone, red alder, black cottonwood, and bigleaf maple appear to be resisters to low to moderate intensity fires, depending on tree size and actual fire intensity. On the left bank, where fire intensity was high, only the larger diameter black cottonwoods were able to resist the flames and heat to reform new leafy crowns in the first postfire year (Figures 2, 3; Table 3). Fire intensity on the right bank was undoubtedly lower compared to the left bank. Representatives of all three species, clearly in the burn zone, resisted the fire and reformed leafy canopies on the right bank in the first postfire year (Figures 3, 4).

These three species should be considered endurers to moderate to high intensity fire, at least, and perhaps resisters to some extent. The characteristics of the Whatcom Creek fire differed from wildland fires (Table 1). Despite the unique nature of this fire event, these species responded positively to fire as an environmental factor. The responses reported here can reasonably be extrapolated to fires in lowland riparian zones. Although these communities seldom burn, low to moderate intensity fires will not produce high mortality among the dominant trees (Tables 2-6). Management fires in riparian communities are not indicated, but if fires burn they should not be viewed as an unmitigated disaster. Postfire rehabilitation should be planned assuming that a high percentage of prefire trees (and much of the understory) will survive the fire, even with 100% CSV and bark scorch (Table 6).

A close examination of Figure 3 reveals recently planted conifer seedlings. Douglas-fir, western redcedar, and western hemlock have been planted extensively in this portion of the burn zone. These species never were present in the riparian community along this portion of Whatcom Creek. Postfire rehabilitation efforts in spring 2000, approved by the City of Bellingham and other trustees

of Whatcom Creek, resulted in thousands of conifer seedlings planted throughout the burned riparian zone west of Valencia Street. Furthermore, an herbicide was applied to understory plants (Figure 4), and bark mulch was spread across much of the burned zone on the left bank, which could interfere with many of the resprouting trees and shrubs. These efforts are misguided for two reasons. Low elevation riparian communities in the Pacific Northwest are characterized by deciduous trees with generally rapid growth rates, grazing food chains, minimal detritus, and many other properties of seral communities described by Odum (1969). The spring 2000 rehabilitation efforts inhibit the normal processes associated with post-disturbance responses. The better course of action would have been to allow the site to recover on its own.

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