Alder Canopy Dieback and Damage in Western Oregon Riparian Ecosystems

Citation	Sims, L., Goheen, E., Kanaskie, A., & Hansen, E. (2015). Alder canopy dieback and damage in western Oregon riparian ecosystems. Northwest Science, 89(1), 34-46. doi:10.3955/046.089.0103
DOI	10.3955/046.089.0103
Publisher	Northwest Scientific Association
Version	Version of Record
Terms of Use	http://cdss.library.oregonstate.edu/sa-termsofuse

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Abstract

We gathered baseline data to assess alder tree damage in western Oregon riparian ecosystems. We sought to determine if Phytophthora-type cankers found in Europe or the pathogen *Phytophthora alni* subsp. *alni*, which represent a major threat to alder forests in the Pacific Northwest, were present in the study area. Damage was evaluated in 88 transects; information was recorded on damage type (pathogen, insect or wound) and damage location. We evaluated 1445 red alder (*Alnus rubra*), 682 white alder (*Alnus rhombifolia*) and 181 thinleaf alder (*Alnus incana* spp. *tenuifolia*) trees. We tested the correlation between canopy dieback and canker symptoms because canopy dieback is an important symptom of Phytophthora disease of alder in Europe. We calculated the odds that alder canopy dieback was associated with Phytophthora-type cankers or other biotic cankers. *P. alni* subsp. *alni* (the causal agent of alder disease in Europe) was not identified in western Oregon; however, *Phytophthora siskiyouensis* was isolated from Phytophthora-type cankers which were present on 2% of red alder trees and 3% of white alder trees. The odds of canopy dieback were 5.4 and 4.8 times greater for red and white alder (respectively) with Phytophthora-type canker symptoms than in trees without such cankers. The percentage of trees with canopy dieback was 51%, 32%, and 10% for red, white, and thinleaf alder respectively. Other common damage included wounding, foliar pathogens and insects on red alder. This is the first report of Phytophthora canker of alder in United States forests and first report of *P. siskiyouensis* isolation from alder in forests anywhere.

Keywords: alder tree damage; *Phytophthora* species; symptoms; riparian ecosystems

Introduction

In 2009, there were numerous reports of alder trees (*Alnus* Miller [Betulaceae]) with canopy dieback in riparian ecosystems in western Oregon. Concern about alder health was heightened because of recent disease problems in Europe caused by the oomycete pathogen *Phytophthora alni* Brasier & S. A. Kirk (Brasier et al. 2004). The invasive *Phytophthora* species was found causing cankers, dieback and mortality of alder trees in 1993 in Great Britain (Gibbs 1995) and subsequently across much of Europe. *Phytophthora alni* was named with three subspecies—subsp. *alni*, subsp. *uniformis,* and subsp. *multiformis* (Brasier et al. 2004, Ioos et al. 2006). *P. alni* subsp. *alni* is considered the most virulent of these (Brasier et al. 2003), and by 2003 it had affected or killed an estimated 15% of alder trees across southern Britain (Webber et al. 2004). *P. alni* subsp. *uniformis* was also found in riparian soils in Alaska (Adams et al. 2008) but was not associated with any dramatic disease. Another *Phytophthora* species, *P. siskiyouensis* Reeser & E. M. Hansen, has been reported killing planted black alder (*Alnus glutinosa* (L.) Gaertn.) in Melbourne, Australia (Smith et al. 2006) and planted Italian alder (*Alnus cordata* (Loisel.) Duby) in California (Rooney-Latham et al. 2009). *P. siskiyouensis* was first described in Oregon forests from blighted myrtlewood (*Umbellularia californica* (Hook. &

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Arn.) Nutt.) shoots and tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Manos et al.) bark cankers (Reeser et al. 2007).

However, no recovery of *P. siskiyouensis* or *P. alni* from alder in Oregon had been described, and it was unknown if Phytophthora canker on alder occurred in forests in the United States. In Alaska, *Phytophthora alni* subsp. *uniformis* was not causing obvious symptoms such as cankers. Historically, damage to alder in the western United States was reported to be caused by other pathogens, insects, and other wound agents such as ice (Worthington and Ruth 1962, Furniss and Carolin 1977, Filip et al. 1989). Our goal was to evaluate the potential causes of alder canopy dieback in western Oregon riparian ecosystems.

Alder trees are ecologically important pioneer plant species distributed across the Northern Hemisphere with their range extending into the Andes of the Southern Hemisphere (Chen and Li 2004). Alder trees are distributed across western Oregon from the Cascade Mountains to the Pacific Ocean. As pioneer plant species, alders inhabit areas inhospitable to most other trees such as newly forming stream banks (Fonda 1974, Hawk and Zobel 1974). Alder root systems provide bank stability (Jensen et al. 1995) and tree canopies shade the water, regulating stream temperatures (Beschta 1997). In the Pacific Northwest, red alder (*Alnus rubra* Bongard) is the most common alder species and is economically important (Harrington 2006). It is an alternative timber tree to Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) in wet locations and locations infested by conifer specific fungal pathogens such as *Phellinus weirii* (Murrill) Gilb., the causal agent of laminated root rot. In western Oregon, alder trees are common along streams, and are a major tree component of riparian ecosystems (Barker et al. 2002) from high to low elevations in both pure and mixed stands (Franklin and Dyrness 1973). Red alder also occurs away from streams, in upland locations on disturbed sites and on planted sites. Two other alder tree species are native to western Oregon. White alder (*Alnus rhombifolia* Nutt.) is a small to medium sized tree found in riparian ecosystems with fine textured soils (Uchytil 1989). Thinleaf alder trees (*Alnus incana* [L.] Moench ssp. *tenuifolia* [Nutt.] Breitung) in western Oregon are found only in the southeastern portions of the region.

Pathogens, insects and abiotic agents damage alders in the Pacific Northwest. Numerous fungal pathogens and saprotrophic decay fungi occur on alder trees. For example, the canker causing pathogen *Neonectria* Wollenw. can be problematic for managed alder (Cootsona 2006). The Pacific Northwest Fungi Database, which contains fungal-host combinations, lists 167 fungi with red alder, 16 fungi with white alder, and 102 fungi with thinleaf alder (Glawe 2009, Shaw 1958). Most fungi, however, cause little or no damage to alders (Harrington 2006).

Numerous insects have been recorded from alder trees in western forests. The Western Forest Insect Collection (Western Forest Insect Card System 2013) includes records for 52 insect species on red alder, 12 on white alder, and 9 on thinleaf alder. Beetles, moths, and sawflies cause periodic damage to alder but most trees recover (Furniss and Carolin 1977). Wound damage has also been reported for alder stands in Oregon. For example, ice storm damage leads to trees with broken tops (Worthington et al. 1962). In eastern Oregon and Washington, floating ice sheets in streams may cause severe wounds to trees in riparian areas (Filip et al. 1989), but this type of severe physical wound is seldom an important factor in western Oregon where winter temperatures are much warmer. However, in riparian areas, debris propelled during flood events can cause significant wounds to trees. Other potential damaging agents are humans, bears, elk, deer, sapsuckers and beavers.

Despite the importance of the tree locally, alder health in riparian ecosystems in western Oregon has not been regularly inventoried. In 2010, we initiated research to assess damage from pathogens, insects, and wounds as possible causes of canopy dieback. Transects were established in riparian alder stands containing both healthy alders and trees exhibiting dieback; signs and symptoms of damaging agents were recorded, then tested for the likelihood of a connection to the observed dieback. The objective was to gather baseline data on damage in western Oregon riparian ecosystems and to examine trees for canker symptoms similar to those caused by the alder Phytophthora in Europe, here termed "Phytophthora-type cankers," which exhibit bleeding lesions, root collar cankers or basal cankers.

Methods

Riparian alder trees in western Oregon (west side of the Cascade Mountains to the Pacific Ocean) were examined between 02 June 2010 and 19 October 2010 within 88 transects 100 m long by 10 m wide. The area was stratified into three sub-regions to assure sampling across all of western Oregon: the Willamette sub-region with streams draining into the Willamette River; the southern sub-region in SW Oregon, and the coastal sub-region with streams draining into the Pacific Ocean (Figure 1). Transects were selected to include alder trees exhibiting canopy dieback and with reasonable access. Transects were not located within 0.5 km linear distance from other transects. A subset of the established transects (18 in the coastal sub-region and one in the Willamette sub-region) were revisited in December 2011 through March 2012, and in October 2012, to follow up on particularly interesting symptoms, especially Phytophthora-type bleeding cankers first observed in the main survey. Five alder trees were sampled for *Phytophthora* species from each transect.

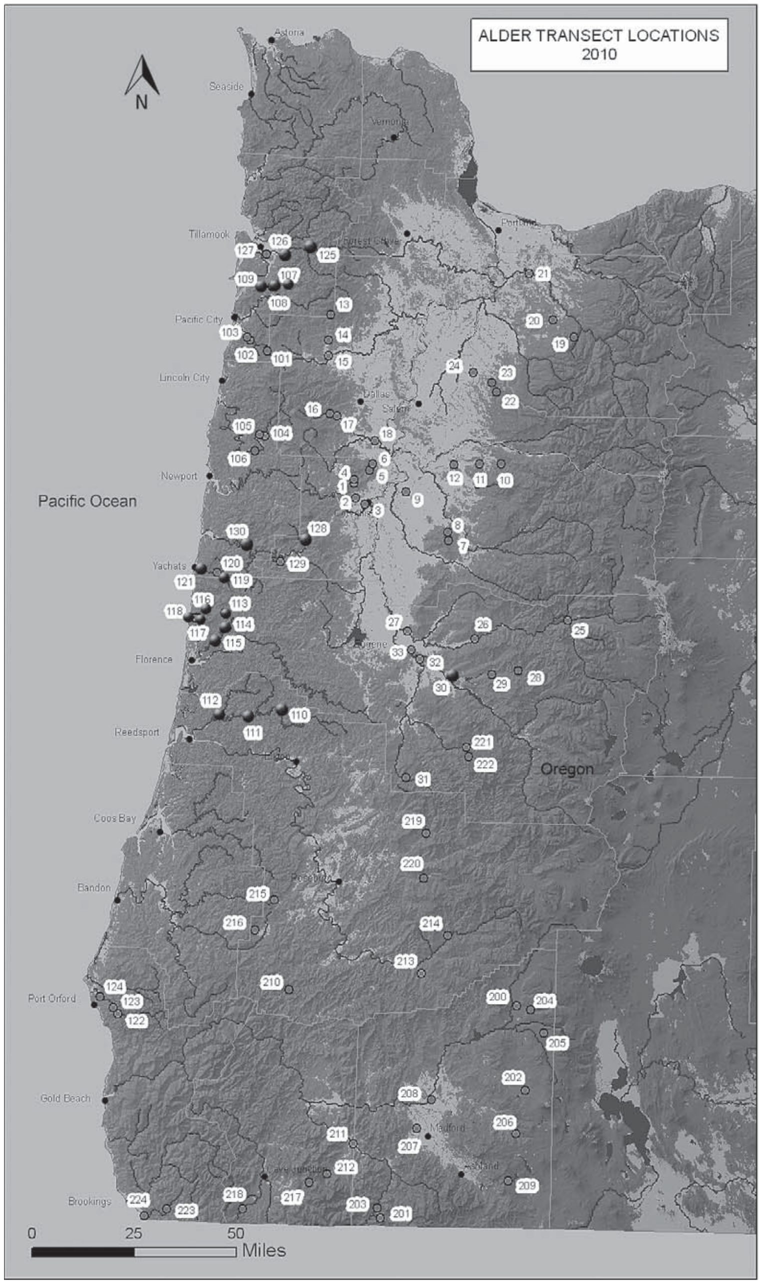

Figure 1. Locations of transects in western Oregon riparian alder ecosystems. Transects are identifiable by black-lined dots; or, by partially shaded circles if they were resampled in 2011–2012. The white patches nearest each dot indicate the transect numbers. Small black dots and names indicate the location of important towns and cities. The area was stratified into three sub-regions to assure sampling across all of western Oregon: the Willamette sub-region with streams draining into the Willamette River (transects numbered 1–33); the southern sub-region in SW Oregon (transects 200–224), and the coastal sub-region with streams draining into the Pacific Ocean (101–130).

TABLE 1. Damage codes recorded for alder trees ≥ 5 cm DBH in western Oregon riparian ecosystems.

Damage (Agents)	Location on Tree	Code	Symptom or Damage Type
Pathogen	stem	SC1	Basal canker or Bleeding Lesion (Phytophthora canker)
Pathogen	stem	SC2	Ascomycete Stem canker
Pathogen	stem	SD	Stem decay
Pathogen	canopy	FPR	Foliar disease: rust
Pathogen	canopy	FPS	Foliar disease: leafspots
Pathogen	canopy	FPO	Foliar disease: other
Insect	stem	SI	Stem boring
Insect	canopy	FIC	Foliage: chewing
Insect	canopy	FIO	Foliage: other
Wound	stem	SW	Stem wound
Wound	canopy	BT	Broken top

Data Collection

Information recorded for alder trees > 5 cm DBH included: tree species, general condition, DBH in 5 cm classes, percent canopy dieback in 10% increments for living canopy dominants, and visible indicators of damage (Table 1), and remarks. The three alder tree species that occur in forests in Oregon were separated mainly by leaf and twig characteristics (Hitchcock and Cronquist 1973). Red alder has revolute, sinuate, broadly elliptic leaves and generally glabrous young twigs. Mountain alder has non-revolute, sinuate or lobed, elliptic or ovate oblong leaves, and strongly puberulent (velvet-like) new twigs and petioles. White alder has non-revolute, finely serrate, oblong to rhombic leaves, and twigs and petioles are not puberulent.

Alder canopy dieback was considered as dead or dying branches and branchlets affecting areas of the canopy that were not shaded (top of the canopy downward or sides exposed to light). Trees with chlorotic or sparse foliage were noted. Current season defoliation from insect or leaf disease was not considered canopy dieback. Understory alder were tallied and measured but were not scored for canopy dieback since alder trees are shade intolerant. Alder tree condition was recorded as living, recently dead (with small attached branches), or old dead.

Damaged plant material and/or insects were collected as necessary for identification. Only visible symptoms of obvious damage were recorded. Identification of pathogens and insects was by morphology and damage patterns. Bark samples were collected from trees with Phytophthora-type cankers (SC1) and plated on oomycete selective media (CARP: cornmeal agar, 10 ppm rifamycin SV sodium salt, 20 ppm Delvocid [50% natamycin salt], 200 ppm ampicillin sodium salt (Reeser et al. 2011). Morphological determination of *Phytophthora* was done on culture plates (CARP and CMAβ: Corn meal agar amended with β-sitosterol). Species identification was confirmed by sequencing of the mitochondrial *Cox* spacer region (Martin and Tooley 2003) and the nuclear ITS (White et al. 1990, Cooke et al. 2000) DNA regions (Sims 2014).

Data Analysis

The association between canopy dieback and causal agents was tested by alder tree species. An odds ratio analysis (Agresti 2007) was performed to evaluate correlations between canopy dieback and Phytophthora-type cankers (SC1) or other biotic cankers (SC2). Analysis included data from living alder trees.

The sample odds ratio θ was defined as:

$$\theta = \frac{\pi_1 / (1-\pi_1)}{\pi_2 / (1-\pi_2)}$$

Success (π) was defined as the proportion of trees with canopy dieback. The probability of success with damage (cankers: SC1 and SC2) was π_1, and the probability of success without damage was π_2. It was assumed that each value fit exactly into only one cell.

For data analysis, 2 x 2 matrices were constructed and the odds ratio was computed using the statistical program R version 2.15.2, (R Core Team 2012). Fisher's exact permutation test for contingency tables (Fay 2010) and Pearson's Chi-squared test (Agresti 2007) were performed for each matrix.

Results

A total of 2729 standing alder trees were tallied on the 88 transects in western Oregon; 421 were dead, including 92 that had recently died. Of 2308 living alder trees 1445 (62%) were red alder, 682 (30%) were white alder, and 181 (8%) were thinleaf alder (Table 2). Red alder occurred in transects from all parts of western Oregon, and was the only alder in the north coastal area. White alder occurred in the southern and Willamette sub-regions. Thinleaf alder occurred on only three transects in the southern sub-region (Table 2).

Canopy Dieback

Of all living alder trees, 981 (42%) had canopy dieback symptoms. The percentage of alder trees with canopy dieback was greater for red alder trees, intermediate for white alder trees and lowest for thinleaf alder trees (Table 2). Trees with dieback were about the same diameter as trees without canopy dieback, except for red alder in the Willamette sub-region where trees exhibiting dieback were slightly larger than trees without dieback, but differences were not significant (data not shown). Several biotic agents, especially pathogens and insects, were found on alder trees associated with damage (Table 3).

Pathogens

Phytophthora-type cankers (SC1) occurred at a low frequency in all sub-regions. They were observed on 57 alder trees including a small percentage of each alder species (Table 4). The odds (based on the odds ratio) of a red alder having both canopy dieback and Phytophthora-type canker were 5.4 times greater than the odds of having canopy dieback without canker damage (Table 5). The odds of a white alder having both canopy dieback and Phytophthora-type canker were 4.8 times greater than the odds of having canopy dieback without canker damage (Table 5). Only one thinleaf alder was tallied with a Phytophthora-type canker, and that tree did have dieback. *P. siskiyouensis* was isolated from one red alder tree with Phytophthora-type canker and canopy dieback in the summer 2010 sampling. The tree was at the northern edge of the southern sub-region (transect 222, Figure 1) leading into the Willamette Valley. *P. siskiyouensis* was isolated from an additional 15 cankers in the follow up winter survey in 2011–2012 from both red alder and white alder. Phytophthora-type cankers (SC1) included both small bleeding lesions (Figure 2, upper right), and large bleeding cankers extending up the main bole of the tree with small bleeding lesions above the main larger

TABLE 2. Alder trees in sampled transects in western Oregon riparian ecosystems by species, dieback status, and diameter. For the columns: 'Canopy Dieback %' was the estimated amount of canopy missing due to dieback on average for each tree, and 'Trees with dieback %' was the overall amount of trees with canopy dieback.

Tree Species	No. trees	No. transects	Mean trees/ transect	Canopy dieback (%)	DBH trees with dieback (cm)	DBH trees without dieback (cm)	Trees with dieback (%)
Alnus rubra	1445	70	21	24	30	23	51
Alnus rhombifolia	682	22	31	26	20	22	32
*Alnus incana**	181	3	60	20	10	10	10

*subspecies *tenuifolia*

TABLE 3. Biotic agents and the associated damage found on alder in western Oregon riparian ecosystems.

Names: Common	Latin	Damage	Reference
Pathogens			
Canopy			
powdery mildew	*Erysiphe* R. Hedw. ex DC.; formerly *Microsphaer*a Lév.	minor leaf damage	Glawe 2006
alder rust	*Melampsoridium* Kleb.	leaf browning, leaf damage	Poldmaa 1997, Pscheidt and Ocamb. 2013
brown leaf blotch	*Mycopappus alni*	large brown foliage spots	Redhead and White 1985
alder leaf spot	*Septoria alnifolia*; *Cylindrosporium alni* Dearn. nomen nudum	necrotic foliage spot often coalescing into larger spots	Constantinescu 1984, Harrington 2006
alder tongue	*Taphrina occidentalis*	catkin deformity	Mix 1949
leaf curl	*Taphrina japonica* Kusano; *Taphrina macrophylla*	deformed curling leaves	Mix 1949
Stem			
Phytophthora canker	*Phytophthora siskiyouensis* Reeser et E. M. Hansen	small to large bleeding cankers and canopy dieback	Rooney-Latham et al. 2009
rough bark canker	*Didymosphaeria oregonensis* Goodd.	roughened outer bark and minor damage on young trees	Goodding 1930
alder nectria canker	*Neonectria major* (Wollenw.) Castl. & Rossman; *Nectria ditissima* Tul. & C. Tul. var. major Wollenw.	Perennial target shaped cankers	Cotsoona 2006
poria	*Phellinus ferruginosus*; formerly *Poria ferruginosa* (Schrad.) P. Karst.	white laminated rot of dead wood	Gilbertson and Ryvarden 1987
Insects			
Canopy			
alder flea beetle; leaf beetle	*Altica ambiens* (Coleoptera: Chrysomelidae	leaf skeletonizing and leaf holes	Furniss and Carolin 1977, Filip et al. 1998
alder woolly sawfly	*Eriocampa ovata* (Hymenoptera: Tenthredinidae)	leaf skeletonizing of l lower leaves	Furniss and Carolin 1977
leafroller	*Epinotia albangulana* (Lepidoptera: Tortricidae)	foliage feeding and leaf rolling	Furniss and Carolin 1977, Miller and Hammond 2002
striped alder sawfly	*Hemichroa crocea* (Hymenoptera: Tenthredinidae)	foliage damage and defoliation	Furniss and Carolin 1977
tent caterpillar	*Malacosoma* species (Lepidoptera: Lasiocampidae)	defoliation	Furniss and Carolin 1977, Miller and Hammond 2002
Stem			
alder bark beetle	*Alniphagus aspericollis* (Coleoptera: Curculionidae) subfamily scolytinae	mine inner bark of damaged trees	Furniss and Carolin 1977
ambrosia beetle	(Coleoptera: Curculionidae) subfamily scolytinae	bore holes in main stem of weak or downed trees	Furniss and Carolin 1977

TABLE 4. The amount and type of damage to alder trees, and the amount of transects containing alders with damage in western Oregon riparian ecosystems. Stem pathogens: SC1 = Phytophthora-type canker, SC2 = other biotic canker, SD = decay. Foliage pathogens (canopy): FPS = spot, FPR = rust, FPO = other. Stem Insects: SI = stem or branch boring insects. Foliage Insect pests: FIC = chewing, FIO = other. Wounds: SW = stem, BT = broken top.

	Damage											
	Pathogens						Insects			Wounds		
	stem			canopy			stem	canopy		stem	canopy	
Alder Species	SC1	SC2	SD	FPS	FPR	FPO	SI	FIC	FIO	SW	BT	n
						trees						
Alnus rubra	2%	3%	4%	22%	0%	1%	3%	34%	1%	20%	5%	1445
A. rhombifolia	3%	3%	9%	4%	0%	4%	4%	3%	2%	21%	3%	682
*A. incana**	1%	5%	0%	3%	0%	0%	1%	9%	2%	38%	5%	181
						transects						
A. rubra	24%	34%	36%	60%	1%	4%	29%	77%	7%	76%	41%	70
A. rhombifolia	36%	41%	50%	36%	0%	18%	32%	18%	14%	77%	27%	22
*A. incana**	33%	100%	0%	33%	0%	0%	33%	67%	67%	100%	100%	3

*subspecies *tenuifolia*

TABLE 5. The odds ratio (θ) that canopy dieback was correlated with canker; and the 95% confidence interval (CI). Pearson's chi-square test and Fisher's exact permutation test for statistical associations.

Damage Indicator	θ	Lower CI	Upper CI	Pearson's Chi-square	Fisher's exact
Phytophthora-type canker:					
A. rubra	5.4	2.1	18.1	0.0002	0.0001
A. rhombifolia	4.8	1.9	14.1	0.0004	0.0004
other biotic canker:					
A. rubra	1.5	0.8	2.9	0.2124	0.1911
A. rhombifolia	1.6	0.5	4.3	0.4795	0.3301
*A. incana**	4.8	0.7	25.2	-	0.0551

canker (Figure 2 arrows, left). Bleeding cankers were sometimes accompanied by dry, cracked bark (Figure 2, bottom right).

Stem cankers of other biotic origin (SC2) had symptoms similar to those caused by several canker-forming ascomycete fungi. SC2 occurred on a small percentage of alder trees. Perennial target shaped cankers were noted most frequently in the Willamette sub-region. Neonectria-type cankers similar to those described by Cootsona (2006) were also observed. Rough bark canker symptoms (Goodding 1930), caused by *Didymosphaeria oregonensis* Goodd. were observed on red alder from the Willamette and southern sub-regions on small (5–10 cm DBH) trees. The odds of a red alder having both canopy dieback and SC2 canker were 1.5 times greater than the odds of having canopy dieback without canker damage (Table 5) and the odds of a white alder having both canopy dieback and SC2 canker were 1.6 times greater than the odds of having canopy dieback without canker damage (Table 5). Neither odds ratio was significant. However, the odds of a thinleaf alder having both canopy dieback and SC2 canker were 4.8 times greater than the odds of having canopy dieback without canker damage (Table 5), and there was suggestive evidence for an association between cankers and canopy dieback (P = 0.06).

Leaf spot symptoms of foliar pathogens (FPS) occurred on nearly a quarter of red alder, but only a small percentage of white alder and thinleaf alder trees (Table 4). Most of the red alder with leaf spot symptoms occurred in the coastal area.

Figure 2. Phytophthora-type cankers on alder trees in western Oregon riparian ecosystems. (Left) Alder tree with Phytophthora-type canker (SC1). The large bleeding canker extended up the bole over 1.5 m with small bleeding cankers continuing to at least 2.5 m (arrows). (Top right) Alder tree with small cankers (chisel blade is 3.7 cm wide). (Bottom right) SC1 ooze on the outside of the bark discolors the outer bark orange, red and dark grey; cankers were sometimes accompanied by dry cracked bark.

Foliar leaf spotting pathogen symptoms occurred in the coastal areas on nearly all transects and almost half of alder trees from that area, but was less frequent elsewhere (Table 4). Two ascomycetes were identified on trees from the coastal areas: *Septoria alnifolia* Ellis & Everh., and *Mycopappus alni* (Dearn. & Barthol.) Redhead & G. P. White. *S. alnifolia* leaf spots were pale brown and circular to irregular, generally 1–2 cm in diameter with a darker margin, and contained clusters of pycnidia in the centers of the leaf spots (Constantinescu 1984). *M. alni* conidiomata were white, mop-like, and consisted of filamentous tufts of conidia that were connected to the leaf tissue (Redhead and White 1985, Funk 1985). White specks (observed with the naked eye) occurred over the brown leaf blotch symptom and were clusters of conidiomata. Leaf spots were 1–5 cm in diameter and were very irregular in shape. Specimens were deposited in the Oregon State University Herbarium (OSC).

Foliar rusts (FPR) were rarely observed (Table 4). Rust was only damaging on a single red alder tree along the McKenzie River. The group 'other' for foliar pathogen related damage (FPO) included leaf tip blight, and leaf curl similar to that caused by *Taphrina japonica* Kusano. Catkin deformity with tongue like enlargements of the bracts of female catkins was observed from nine white alder trees and was identified as *Taphrina occidentalis* W. W. Ray (Mix 1949): some of the same trees had galled and curled areas on the leaves. Catkin deformity was observed from a few transects in southern Oregon and the Willamette Valley.

Basidiocarps of wood decay fungi on living alder trees were infrequently encountered. *Phellinus igniarius* (L.) Quél was not identified. *Phellinus ferruginosus* (Schrad.) Pat. was observed on attached dead lower branches and on fallen branches of white alder. Attached dead branches with characteristic resupinate conks were not considered stem decay damage, as the infection only appeared in branches. *P. ferruginosus* was also observed on one large diameter living red alder with compartmentalized decay; it was growing on the dead portion of the stem, consistent with its role as a saprotroph of dead wood of hardwoods (Gilbertson and Ryvarden 1987). Pleurotoid fruiting bodies were observed on old dead trees, and rarely on large living trees with evidence of extensive decay. Observation of annual fruiting structures was limited by the time of year when the survey was conducted. However, stem decay occurred in about a third of red alder transects and half of white alder transects (Table 4). Stem decay was often noted in trees with no obvious fungal signs, but was indicated by woodpecker cavities and old wounds with dead and decayed wood. Decayed areas were easily recognized beneath bark because they gave way when struck lightly with the blunt side of a hatchet. Stem decay occurred with about equal frequency in trees with and without dieback.

Insects

Damage by stem insects (SI) such as ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) were on dead trees, and the bark beetle *Alniphagus aspericollis* (Coleoptera: Curculionidae: Scolytinae) was relatively infrequent. Stem insect damage occurred on a small percentage of all alder species trees (Table 4). Foliage feeding insect damage was much more common.

Foliage feeding insect (FIC) damage was most common and occurred on about a third of red alder trees. The FIC occurred on a small percentage of white alder and a slightly greater percentage of thinleaf alder. Flea beetle larvae of *Altica ambiens* (Coleoptera: Chrysomelidae) and sawfly larvae of *Eriocampa ovata* (Hymenoptera: Tenthredinidae) were common on red alder. Tent caterpillars (*Malacosoma* species (Lepidoptera: Lasiocampidae)) were infrequent on red alder and white alder, but have been important damage agents in the past (Worthington and Ruth 1962, Gara et al. 1978, Filip et al 1998). Other insect related damage (FIO) was very minor, and was from aphids (Hemiptera: Aphididae), leaf rolling insects such as *Epinotia albangulana* (Lepidoptera: Tortricidae), spittlebugs (Hemiptera: Cercopidae), and leaf mites (Arachnida: Trombidiformes: Eriophyidae). FIO damage was minor and affected very few alder trees (Table 4).

Wounds

Trees with stem wound damage (SW) occurred frequently on all species of alder in western Oregon (Table 4). Damage was mainly from riparian debris. In general, stem wounding was not associated with canopy dieback.

Alder trees with broken tops were scattered across western Oregon, but relatively infrequent (Table 4). Most broken tops were probably the result of past ice storms. Many trees with old broken tops had regenerated full canopies. Broken tops occurred with about equal frequency on trees with and without dieback.

Discussion

Alder health is of special concern in Oregon because of the tree's importance ecologically and economically to the region, and because of reports of the destructive epidemic of the invasive alder *Phytophthora* in Europe and recent reports of a variant of *P. alni* in North America (Adams et al. 2008, Aguayo et al. 2013). Indeed, fear that the alder *Phytophthora* was already in Oregon provided the motivating force for this project. Because *P. alni* is most readily identified in Europe from bleeding lesions, basal cankers, and root collar cankers on tree boles, we concentrated on similar bole canker symptoms. *P. siskiyouensis* was isolated from a Phytophthora-type canker in the initial survey of 88 transects, and from 15 additional cankers in the follow up isolations from cankered trees on 18 transects. None of the subspecies of *P. alni* were isolated from bole cankers in western Oregon. In a parallel but separate root survey, *P. alni* subspecies *uniformis* was isolated four times from necrotic roots. However, *P. siskiyouensis* was isolated 30 times from roots in the same follow up sampling. *P. alni* subsp. *uniformis* is known from Alaska (Adams et al. 2008) as well as Europe. It is less aggressive to alder than *P. alni* subsp. *alni* in Europe (Brasier 2003), and may be native to western North America (Aguayo et al. 2013).

Phytophthora-type canker damage (Figure 2) was strongly correlated with canopy dieback based on the odds ratio. Symptoms of SC1 damage were widespread in the region but relatively infrequent. Initial isolation success for *P. siskiyouensis* may have been low due to summer sampling in the 2010 fieldwork. This is the first isolation of *P. siskiyouensis* (or any *Phytophthora*) from alder cankers in natural stands in North America.

Mature alder trees with canopy dieback were commonly observed in western Oregon, but no single agent was the likely causal factor. Instead, it is likely that canopy dieback results from several abiotic and biotic factors. In this work, Phytophthora-type cankers were strongly associated with red alder and white alder trees exhibiting canopy dieback (Table 4), but such cankers only occurred on 2–3% of the trees in the transects. Other agents not identified here must be involved as well, probably including root pathogens and abiotic factors such as changing water levels.

Although presence of canopy dieback was a transect selection criterion, it was not difficult to locate suitable transects. Canopy dieback in living alder trees was generally recent because branches and branchlets remained on most symptomatic trees. If trees had both recent dead areas of the canopy and old dead areas, it would suggest that the progression of the trees to death was very slow. This was not generally the case.

Other biotic cankers besides Phytophthora were not associated with canopy dieback for red alder and white alder (Table 4). However, there was suggestive evidence ($P = 0.06$) that other biotic cankers, probably Cytospora canker, were associated with canopy dieback for thinleaf alder; and the odds of a thinleaf alder having both canopy dieback and SC2 canker were much greater than the odds of having canopy dieback without canker damage (Table 5). *Cytospora* and *Valsa* species are important in causing disease on thinleaf alder in the western United States (Worrall et al. 2010, Stanosz et al. 2011) including in northeastern Oregon where thinleaf alder is much more common (Filip et al. 1992).

Foliar pathogens have not been associated with important damage to mature alder trees in natural settings, although *Mycopappus alni* in British Columbia has been reported to be the cause of early defoliation in understory alder trees (Redhead and White 1985), and *Septoria alnifolia* has been noted to cause economic losses in nursery settings (Harrington 2006). In the coast sub-region of western Oregon in particular, foliar leaf spot pathogens on red alder may be under-appreciated as damaging agents because they were widespread on a high proportion of trees.

Stem decay was not associated with canopy dieback. Stem decay was as common in trees with as without dieback. In a study in Victoria, BC, it was found that red alder readily compartmentalized stem decay and that stem decay did not spread much beyond previously injured tissue (Allen 1993). If stem decay was mainly associated with localized damage it would not be expected to result in canopy dieback.

Insects

Foliar insects were associated with damage in about a quarter of the alder trees in our transects. The defoliating insects observed here have caused periodic defoliation to alder trees elsewhere.

Damage was mainly attributed to flea beetles *Altica ambiens,*(Coleoptera: Chrysomelidae) and the larval stage of sawflies, such as *Hemichroa crocerea* (Hymenoptera: Tenthredinidae) and *Eriocampa ovata* (Hymenoptera: Tenthredinidae). Tent caterpillars (*Malacosoma* species (Lepidotera: Lasiocampidae)) were infrequently causing damage, but have been important damage agents in the Pacific Northwest in the past, and are known to cause periodic severe defoliation. If defoliation remains high for several years, dieback may occur but most trees will survive (Worthington and Ruth 1962).

Bark beetles (Coleoptera: Curculionidae: Scolytinae) were not found on many trees. Where they were present, they appeared on larger (older) alder trees, consistent with the secondary nature of many bark and wood attacking insects. However, in a few locations with heavy accumulation of alder logs there was also heavy damage from bark beetles (Coleoptera: Curculionidae: Scolytinae) on standing trees.

Wounds

Most stem wounds resulted from debris swept by the flow of high water into tree boles; these were identified by wounds on the upstream side of the lower bole of trees. Other stem damage resulted from nearby falling trees. Sapsucker damage was not frequent, but did occur heavily in a few transects in the southern Oregon area. Bear and beaver damage was observed infrequently. Human damage was not common in these transects, but included chopping, damage from wrapped wires, bark carving, and anthropogenic debris propelled into trees by floods. Broken tops were mainly attributed to ice storms. It has been suggested that red alder is more susceptible to ice damage than conifers, but that trees appear to recover (Worthington and Ruth 1962) by regenerating a new canopy. Although these wounds were widespread and frequent in some cases, they were not especially associated with dieback.

Conclusions

- *Phytophthora alni* subsp. *alni,* an important pathogen in Europe, was not identified in western Oregon.
- Canopy dieback in alders is common but no single agent was detected. Instead, dieback appears to be the result of several factors.
- Phytophthora-type cankers were present on alder trees in western Oregon riparian ecosystems, mainly on red alder and white alder trees. This type of damage is strongly correlated with canopy dieback. *P. siskiyouensis* was isolated from alder trees with Phytophthora-type cankers in western Oregon. This is the first report of Phytophthora canker on alder in natural stands in the United States and first report of *P. siskiyouensis* isolation from alder in forests anywhere.
- Foliage pathogens were observed on many red alder trees in coastal areas, but did not appear to be important damaging agents elsewhere.
- Foliage feeding insects were found on 34% of red alder in western Oregon riparian ecosystems.
- Wounding to alder trees of all species was relatively common in riparian areas.
- Several different agents, including *Phytophthora*, are the likely causes of canopy dieback.

Acknowledgments

We thank Wendy Sutton and Paul Reeser for laboratory support. We thank Michael Thompson, Jon Laine, Aaron Wichman, and Jenny Oberst for field support. Special thanks to Sarah Navarro for her help with the alders. Thank you to Jeff Stone for his comments on an early version of the manuscript. Thanks to the Oregon State Arthropod Collection group for assistance with arthropod related information. Thanks to the Oregon State University Herbarium group for assistance with vascular plants and fungal specimens. The Forest Health Protection Program, Rogue Siskiyou National Forest and the Oregon Department of Forestry provided funding support. We also thank two anonymous reviewers for helpful comments that improved the manuscript.

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Received 17 March 2014

Accepted for publication 9 September 2014