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Rubus armeniacus (Himalayan blackberry) Occurrence and Growth in Relation to Soil and Light Conditions in Western Oregon

Abstract

Rubus armeniacus (Himalayan blackberry) is an invasive plant in disturbed habitats in the Pacific Northwest. At 41 sites dominated by *R. armeniacus*, we measured stand height, mean floricane length, canopy cover, slope, aspect, and soil properties (color, NO_3+NO_2–N, organic matter, particle size distribution, and pH). For several soil properties we compared our data to National Resource Conservation Service soil survey data for the soils near our sites. *R. armeniacus* occurred in soils that contained more sand (by 25.6%, $P < 0.001$), less silt (by 9.4%, $P = 0.03$) and less clay (by 13.4%, $P < 0.001$) than this non-biased, random sample of western Oregon soils. Ln(stand height) was significantly related to canopy cover ($R^2 = 0.44$, $P < 0.001$) and floricane length was significantly related to gravel ($R^2 = 0.11$, $P = 0.03$). Our results suggest that shade was a primary environmental determinant of *R. armeniacus* occurrence and growth. Our results further suggest that *R. armeniacus* is tolerant of a wide range of soil conditions, notably coarse texture. An ability to withstand soils with low water content or low nutrient availability with only a small reduction in growth may explain *R. armeniacus* occurrence on more coarse-textured substrates than are typical for western Oregon soils. In combination with its adaptation to high light availability conditions, this factor may help explain the frequent occurrence of *R. armeniacus* in anthropogenically disturbed habitats.

Introduction

Human-caused landscape alterations can affect the distribution and quality of environmental resources in ecosystems such that pre-adapted non-native plants can colonize and compete with native plants (Bazzaz 1983, 1986; Richardson et al. 1996). For the large subset of plant invasions associated with disturbance, information on photosynthetically active radiation (hereafter termed simply light) and soil resource use can help determine how disturbance facilitates invasion, and can help guide management activities (Hobbs and Humphries 1995). *Rubus armeniacus* Focke (Himalayan blackberry, *R. discolor* Weihe & Nees, *R. procerus* P. J. Müll; Evans and Weber 2003) is an invasive plant in the Pacific Northwest (PNW) for which prevention, control, and restoration could be improved if ecosystem managers had better information on its resource preferences in disturbed environments.

R. armeniacus is native to the Caucasus region of Eurasia, and was introduced to the PNW in the late 1800s for cultivation (Jennings 1988). This invasive species is now widely established in northern California, Oregon, Washington, and British Columbia (Hitchcock and Cronquist 1973) and is listed by California and Oregon as a weed of concern (Cal-EPPPC 1999, ODA 2003). *R. armeniacus* also occurs in the Snake River valley (Hitchcock and Cronquist 1973) and may be colonizing other regions east of the Cascades (Dennis Isaacson, Oregon Department of Agriculture (ODA), personal communication). Invasive blackberry species interfere with agriculture and silviculture (ARS 1968, Cain and Shelton 2003, Fotelli et al. 2005) and dominate areas that would otherwise be occupied by higher quality wildlife habitat such as native plants communities (O'Neill 1999, Perritt et al. 2004). *R. armeniacus* may create a fire hazard by producing a large biomass of senesced canes, harbor vectors for disease, form barriers, and incur high control costs (Dutson 1973, Hoshovsky 2000). Moreover, *R. armeniacus* can be indirectly responsible for waterways becoming contaminated by herbicides due to improper control efforts (Dennis Isaacson, ODA, personal communication).

Several life history traits may contribute to *R. armeniacus* invasiveness in the PNW, as indicated by research on *R. fruticosus* L. (wild blackberry, an aggregate taxon that includes *R. armeniacus*; Jennings 1988) carried out in Australia and Europe, and by prior work on *R. armeniacus* in Oregon. *R. armeniacus* grows rapidly and reproduces by both clone and seed production (Amor 1974). Phenologically, *R. armeniacus* segregates growth

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and reproduction such that it can devote a significant portion of its resources to reproduction, which results in large seed crops (720 fruits per cane; McDowell and Turner 2002) for dispersal by birds and other animals (Gervais et al. 1998, Hoshovsky 2000). *R. armeniacus* competes effectively with other plants for water, nitrogen, and light (Fotelli et al. 2001, 2002, 2005) and is efficient at acquiring carbon (McDowell 2002). It also deters herbivores with prickles and tomentose leaves (Hitchcock and Cronquist 1973) and one of its main pathogens in Eurasia, the fungal rust *Phragmidium violaceum*, was not found in the PNW until recently (Osterbauer et al. 2005).

R. armeniacus most commonly invades disturbed habitats in the PNW (Dutson 1973, Hoshovsky 2000). Disturbance, and especially anthropogenic disturbance, could facilitate *R. armeniacus* invasion by making space, light, and soil resources more available. Despite the potentially important role of habitat disturbance and resource use in *R. armeniacus* invasion, prior research has not investigated its resource tolerances or growth response to light and soil resources in the PNW. Our study sought to determine: (1) *R. armeniacus* tolerance limits for soil and light characteristics in western Oregon, (2) how the soil conditions in which *R. armeniacus* occurs compare to typical soil conditions for western Oregon, and (3) which resources limit *R. armeniacus* stature and annual growth.

Methods

We established 41 sites across an elevation gradient (~600 m relief) spanning the Willamette River Valley and the Western Cascade Range in Oregon (Figure 1). To ensure sites would not be biased

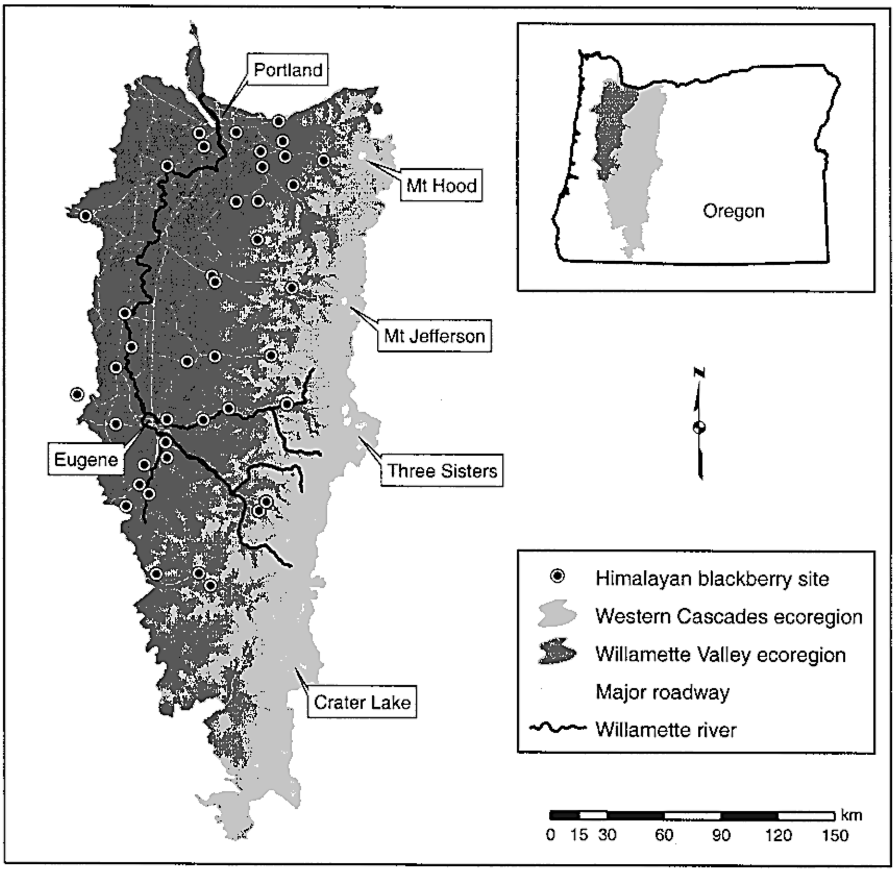

Figure 1. *Rubus armeniacus* sample site locations in western Oregon. The inset map shows the locations of the Willamette Valley and Western Cascade ecoregions within Oregon. Shading in the larger map denotes elevation.

TABLE 1. Growth and environmental characteristics measured for *Rubus armeniacus* stands or the sites at which it was growing. Aspect values were calculated only for sites on slopes over 20%. Percentage units for soil properties are by weight except for gravel, which is by volume.

	Minimum	Median	Mean (SE)	Maximum
Floricane length (cm)	55	91	92 (3.3)	144
Stand height (m)	0.8	1.5	1.5 (0.1)	3.4
Canopy cover (%)	0	20.7	30.2 (4.4)	88.4
Slope (%)	0	12	19 (4)	90
Aspect (deg)	n/a	175	178 (18)	n/a
Elevation (m)	23	226	253 (4)	621
Hurst color	11.7	25	26.2 (1.1)	53.8
pH	4.2	5.3	5.3 (0.1)	6.3
Organic matter (%)	1.4	9	9.1 (0.6)	16.7
NO_3+NO_2–N (ppm)	39	495	1170 (281)	8740
Gravel (%)	0	2.6	7.1 (1.5)	37.3
Sand (%)	5.8	38.2	40.2 (3.0)	77.8
Silt (%)	16.5	46.9	48.5 (2.7)	80.4
Clay (%)	0.7	11.3	11.3 (1.0)	32.7

in their distribution on the landscape scale, we randomly selected 1 km^2 reference areas within 5 km of all major roadways in the Willamette Valley and Western Cascade ecoregions. We selected sites on the local scale by random encounter, with the criteria that the following land use types be represented: roadsides, parks, riparian areas, agricultural areas, residential yards, and clear-cuts. Most sites were within 10 km of a randomly selected reference area. We only chose sites where *Rubus armeniacus* had formed nearly monospecific stands at least 10 m^2 in area, and where leaves showed no visual evidence of herbicide application (yellow mottling or premature necrosis). These conditions ensured interspecific competition and chemical interference would not confound the effects of light and soil properties on growth.

We measured mean floricane length, stand height, and 12 environmental variables (Table 1) at each site during August or September, 2002. We established three transects from the stand margin through the stand interior, and selected 10-16 floricanes (annual flowering canes) at ~1 m intervals along the transects for length measurement (± 1 cm). *R. armeniacus* completes its floricane growth before fruiting in July (McDowell and Turner 2002), so our cane length measurements reflected cumulative growth during the 2002 growing season. We also estimated stand height (± 30 cm) at a representative point near the center of each stand; we adjusted the estimate if a visual assessment of the stand's canopy surface suggested our initial value was biased. For each of the three transects in a stand, we took a soil sample >1 m inside the stand margin and measured canopy cover with a spherical densiometer. We did not measure light directly because we visited sites at different times of the day and under different cloud conditions; however, densiometer measurements of canopy cover have been strongly correlated with light availability (Comeau et al. 1998, Englund et al. 2000, Ringold et al. 2003). We recorded elevation, slope, and aspect once per site.

We measured chemical and physical soil properties including nitrogen content (NO_3+NO_2–N), organic matter content, pH, color, and particle size distribution. We measured all properties for each horizon present in the top 30 cm of soil under each transect (or in four cases, to the maximum depth we could obtain a sample). We selected a 30 cm depth so samples would represent *R. armeniacus*' potential rhizosphere; Amor (1972) measured 77% of *R. fruticosus*' root mass in the upper 20 cm of soil in Australia. With the exception of color, we measured all soil properties from samples dried at 105°C. We determined NO_3+NO_2–N by colorimetry with a Milton Roy Spectronic 401 spectrophotometer, following extraction with 2 M KCl and cadmium reduction (Jones 1984, Mulvaney 1986). We selected the soil nutrient NO_3+NO_2–N rather than PO_4–P or NH_4–N because nitrogen tends to be the limiting nutrient in western Oregon soils (Sollins et al. 1980) and because caneberries take up NO_3 more readily than NH_4 (Hart et al. 1992). We determined organic matter content by combustion (Carter 1993) and we measured pH in a 1:1 slurry of dry soil and deionized water (Thomas 1996). We rated soil colors (Munsell system codes) on the Hurst index, which assigns high values to yellow or pale soils and low values to red or dark soils (Hurst 1977). We used the average of moist and dry Hurst color values for data analyses. We combined samples from the three transects for particle-size analysis, except where horizons differed among transects. We separated gravel (> 2 mm) and coarse sand (0.5-2 mm) by dry sieving, separated fine sand (63-500 µm) by wet sieving, and performed hydrometer analysis to determine the silt (2-63 µm) and clay (< 2 µm) fractions (Gee and Bauder 1986).

We computed composite site values for canopy cover and soil properties by taking the mean of the values from each of the three transects or core samples. For soil properties, we weighted sample values by horizon depth before calculating the composite site value:

$$\text{Depth-weighted value} = \Sigma\,(D_i \cdot P_i) \qquad (1)$$

where D_i is horizon i's fraction of the soil core's depth and P_i is the value of property P in horizon i (Yeakley et al. 1998).

To determine if *R. armeniacus* occurrence was related to aspect, we tested the significance of the mean aspect with a Rayleigh test (Zar 1984). The Rayleigh test determines if angular values are distributed randomly about a circle or if there is a significant trend toward a given direction (i.e., if there is a meaningful mean angle). Because aspect influences light availability more strongly on steeper slopes than shallow slopes we applied the Rayleigh test to the subset of sites with slopes over 20% (n = 10).

To determine if *R. armeniacus* occurrence was related to one or several soil properties we compared our data on soils under *R. armeniacus* stands to data from a representative sample of western Oregon soils. We used the set of soil map units surrounding our sites as the representative sample so we could make a non-biased comparison with our data. We excluded seven of our sites from the comparison because National Resource Conservation Service (NRCS) soil surveys did not describe the soil map units surrounding those sites. Of the properties we measured, pH, organic matter content, and particle size data were reported by the soil surveys. Because NRCS soil surveys report data ranges rather than means or medians, we averaged the two values given for each horizon in the upper 30 cm, and used the resulting mean to determine a depth-weighted value with Equation 1. Three sites overlaid soil map units that were complexes of multiple soil types; for those we computed weighted averages of each soil type according to its areal coverage. We used Mann-Whitney rank-sum tests to compare median pH, organic matter, gravel, sand, silt, and clay content from locations where *R. armeniacus* was present to median values for the corresponding soil map units (n = 34). A non-parametric test was necessary because several variables failed Anderson-Darling tests of normality.

We used stepwise multiple linear regression (SMLR; n = 41) to determine which environmental variables limited *R. armeniacus* growth in our samples. We performed separate regression analyses for stand height and mean floricane length (response variables), using the same pool of independent variables (Table 1, excluding silt and aspect). Silt and sand were highly correlated (Table 2); we did not include silt to prevent

TABLE 2. Pearson correlations between measures of *Rubus armeniacus* growth (stand height, floricane length) and environmental variables (n = 41). Only significant correlations ($P < 0.05$, two-tailed) are shown.

	Length	Height	Canopy	Slope	pH	Org Mat	Color	Nitrogen	Gravel	Sand	Silt	Clay
Height	-											
Canopy	-	-0.6										
Slope	-	-	-									
pH	-	-	-	0.3								
Org Mat	-	-	-	-	-							
Color	-	-	-	-0.3	-	-0.4						
Nitrogen	-	-	-	-	-	-	-					
Gravel	-0.33	-	-	-	0.39	-	-	-				
Sand	-	-0.31	0.43	-	-	-0.3	-	-	0.35			
Silt	-	-	-0.36	-	-	-	-	0.32	-0.32	-0.94		
Clay	-	-	-0.33	-	-0.31	0.38	-0.47	-		-	-0.46	
Elevation	-	-0.32	-	0.31	0.33	-	-	-	-	-	-	-

multicollinearity errors (Graham 2003). We did not include aspect because it was undefined at sites that had zero slope. We standardized environmental variables to further reduce multicollinearity (Gunst and Mason 1980). We applied a natural log transformation to stand height because residuals were not normal without the transformation. This transformation did not affect the identity of the variables selected by the stepwise procedure. We computed Pearson correlation coefficients for all growth and environmental variables (excluding aspect) to determine which environmental variables were related, and which may have influenced *R. armeniacus* growth but not been selected by SMLR. We evaluated all statistical tests at a significance level of $P = 0.05$.

Results

Rubus armeniacus stands were present under open to nearly closed canopies (0-88% canopy cover) and on shallow to steep slopes (0-90%) (Table 1). Stands on slopes over 20% had a significant, southerly mean aspect ($\bar{A} = 178°$, $P < 0.05$). All stands were below 625 m elevation. We observed *R. armeniacus* in soils with dry colors ranging from light brownish gray (Munsell: 2.5Y 6/2, Hurst: 53.8) to red (Munsell: 10YR 4/6, Hurst: 11.7), across a large range of soil organic matter, and in acidic to neutral soils (Table 1). *R. armeniacus* was present on soils with a large range of extractable NO_2+NO_3–N, and textures ranging from loamy sand to clay loam to very gravelly silt loam (Table 1).

Comparison of soil conditions in which *R. armeniacus* was present with conditions representative of the soil types of the surrounding areas showed several pronounced differences (Figure 2). In the *R. armeniacus* stands we measured, median soil pH was 0.6 units lower ($P < 0.001$), and organic matter content was 5.3% higher ($P < 0.001$) than

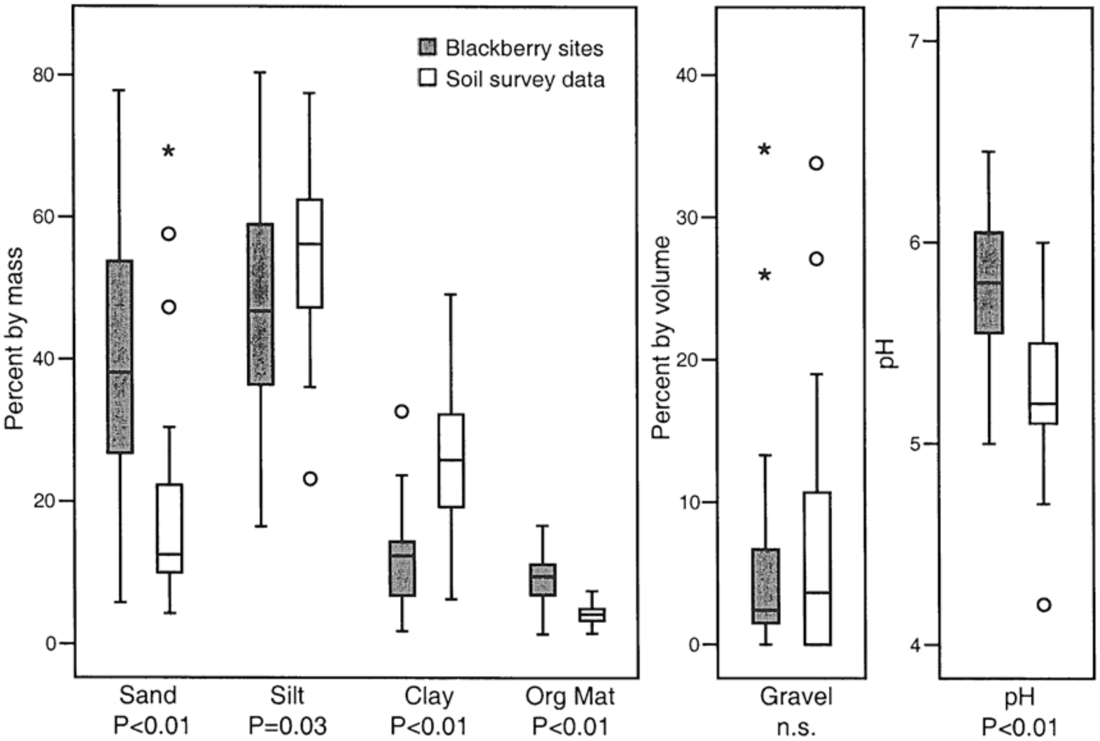

Figure 2. Soil characteristics at 34 sites in western Oregon dominated by *Rubus armeniacus* and for the NRCS soil survey map units in which the sites were located. Boxes represent the middle 50% of data values, with medians denoted by stripes through the boxes. Whiskers extend to the furthest data point within 1.5x the interquartile range, with circles and asterisks denoting data points more than 1.5x and 3x the interquartile range from the median, respectively. P-values are shown for Mann-Whitney median comparisons.

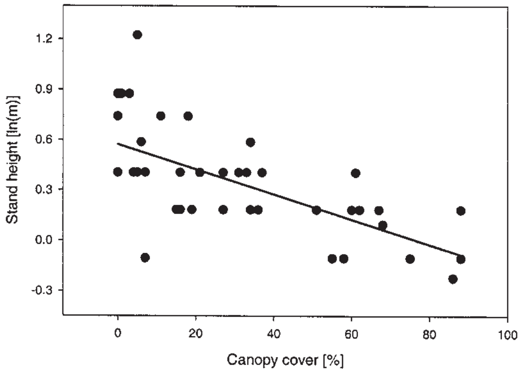

Figure 3. Relationship between *Rubus armeniacus* stand height (natural log transformed) and canopy cover. Regression line has $R^2 = 0.44$ and $P < 0.001$.

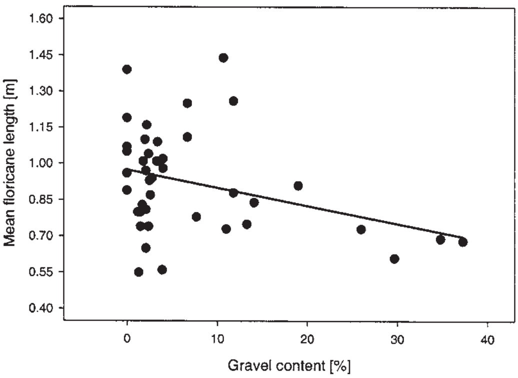

Figure 4. Relationship between *Rubus armeniacus* floricane length and soil gravel content. Regression line has $R^2 = 0.11$ and $P = 0.035$.

in the surrounding soil map units. Median gravel content was not significantly different between *R. armeniacus* sites and the surrounding soil map units, but sand content was 25.6% greater ($P < 0.001$), silt was 9.4% lower ($P = 0.032$), and clay was 13.4% lower ($P < 0.001$) in *R. armeniacus* stands.

Stepwise multiple linear regression (SMLR) for stand height selected only canopy cover as an independent variable ($R^2 = 0.44$, $P < 0.001$, Figure 3), while SMLR for floricane length selected only gravel content ($R^2 = 0.11$, $P = 0.035$, Figure 4). Stand height was also correlated with sand content and elevation (Table 2).

Discussion

The reason *Rubus armeniacus* frequently occurred in exposed conditions (low canopy cover and slopes facing, on average, approximately south) may be that it is better adapted to high than low light conditions. This explanation is consistent with the finding that photosynthesis saturates at a higher irradiance in *R. armeniacus* than in two of its congeners native to the PNW (Barber 1976). *R. armeniacus*' frequent occurrence in exposed conditions may have also come from an adaptation to the moisture, nutrient, or temperature conditions that resulted from elevated irradiance and reduced overstory detrital input. The weak, but statistically significant, correlations among canopy cover, soil texture variables, and soil nitrogen content (Table 2) are consistent with this interpretation. Although *R. armeniacus* occurs more frequently in areas with lower tree density (Gray 2005), we observed monospecific stands where canopy cover was as high as 88%. This result suggests that canopy cover, while the primary factor, may not be the only factor controlling *R. armeniacus* stand distribution.

The high sand, low silt, and low clay content of our samples relative to those reported in the NRCS soil survey data show that *R. armeniacus* can be frequently found in habitats with more coarse-textured substrates than is typical for western Oregon soils. The median soil texture in *R. armeniacus* stands had lower water holding and cation exchange capacities than the median texture of the corresponding map units (Black 1968). The wide range of soil textures in which we found *R. armeniacus* suggests that it can tolerate drier moisture regimes than are typical for western Oregon soils. These results also suggest, however, that *R. armeniacus* does not require coarse-textured soil. Tolerance of low soil moisture by *R. armeniacus* is consistent with its high rating on a moisture stress gradient in Oregon (Ohmann and Spies 1998) and with the ability of invasive *R. fruticosus* to maintain its water status and biomass during drought conditions (Fotelli et al. 2001, McDowell 2002).

The elevated median level of organic matter at our sites relative to the soils surrounding them was likely due to *R. armeniacus* producing organic detritus. Stem and leaf fragments (< 2 mm) identifiable as *R. armeniacus* were common in our soil samples. Many of our sites had fill or gravelly substrates that would have supported little vegetation prior to colonization by *R. armeniacus*, suggesting that the high organic matter was a result, not a cause, of *R. armeniacus* presence. Organic matter from *R. armeniacus* detritus may have increased the moisture content at our sites with coarse-textured substrates (Homann et al. 1995, Yeakley et al. 1998), which would help explain stand maintenance (but not necessarily establishment) at these sites.

The range of soil pH in which we observed *R. armeniacus* demonstrates that it is tolerant of acidic soils, but does not address its tolerance for alkaline soils. *R. armeniacus* is present in PNW habitats east of the Cascades (Dennis Isaacson, ODA, personal communication), which have predominantly alkaline soils, and invasive blackberry species occur on both acidic and alkaline soils in Australia (Amor et al. 1998). Because organic matter is a source of soil acidity (Birkeland 1999), the occurrence of *R. armeniacus* on sites with below-median pH is consistent with their occurrence in soils with elevated organic content due to detrital input. Given the risk of *R. armeniacus* invasion in ecosystems east of the Cascades, a more detailed assessment of its tolerance of alkaline soils is warranted.

Within the range of environmental conditions and resources *R. armeniacus* can tolerate, both light and soil properties potentially limit its growth. The inverse relationship displayed by stand height and canopy cover indicates that *R. armeniacus*' vertical growth may be predominantly controlled by light availability. A potential implication of this limitation is that thicket expansion by stolon rooting could be slower with more shade. Because shoots that contribute to stand height (i.e., primocanes) are in great part responsible for clone expansion by arching over and rooting at their tips (Amor 1974), stands of shorter stature may be unable to expand as readily as taller ones. This explanation is consistent with a study that found *R. armeniacus* cover to be negatively correlated with overstory canopy cover (at high levels of canopy cover) in forested sites across western Oregon (Gray 2005). While *R. armeniacus* can establish and survive on relatively coarse-textured soils, the inverse correlation between mean floricane length and gravel content suggests that the diminished soil water or nutrient content of gravelly substrates can slow the growth rate of the plant's non-reproductive floricane tissue. The fact that floricane lengths were highly variable at low to moderate gravel contents (Figure 4) indicates that gravel has less influence on floricane growth in less gravelly soils than in very gravelly soils.

R. armeniacus' ability to persist under soil conditions that were more extreme than median western Oregon conditions (i.e., its frequent occurrence in substandard soils) may indicate that it can competitively displace plants that require more available soil water or nutrients (Tilman 1982). *R. armeniacus*' tolerance of dry, low nutrient soils presumably comes from the fact that it experiences fewer stress-induced trade-offs than other plants. This possibility is consistent with the absence of photosynthetic trade-offs displayed by *R. armeniacus* during reproduction (McDowell and Turner 2002) and the elevated competitive ability of *R. fruticosus* under simulated drought conditions (Fotelli et al. 2001, 2002).

If *R. armeniacus*' reduction in growth under poorer soil conditions is small relative to the advantage it gains over competitors, this would help to explain the proliferation of the species in anthropogenically disturbed habitats. Human activities, such as road building and urban development, distribute coarse-textured fill and gravel (Untermann 1978, Jim 1998) and fragment overstory vegetation (Rebele 1994, Spellerburg 1998), and thus provide a light and soil resource regime well suited to *R. armeniacus*.

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