CIPM SEED Grant 2005 Report (awarded 2004)
TITLE: Invasion by *Buddleja davidii*: potential impacts to the geomorphology of a gravel bar on the Tolt River, Washington.

To: Janet K. Clark, Director
Center for Invasive Plant Management
Montana State University
Bozeman, MT 59717-3120

From: Principle Investigator: Sarah Reichard, Associate Professor
Primary Researcher: Jennifer Leach, M.S. Student
University of Washington
University of Washington Botanical Gardens
Box 354115
Seattle, WA 98195-4115

Abstract adapted from original thesis proposal

Butterfly bush (*Buddleja davidii*, family Loganiaceae) is a semi-deciduous shrub native to river bars in central China. Prized for its dense panicles of colorful flowers, tolerance of a range of soil conditions, and its ability to attract a large number of butterflies to the garden, *Buddleja* has become widespread around the globe through introduction as an ornamental. As land managers in Washington state increasingly report dense thickets of escaped populations along roadsides, river gravel bars and pastures, there is growing concern regarding the impact of *Buddleja* on these ecosystems. In riparian zones of the Pacific Northwest, *Buddleja* is functioning as a pioneering species, colonizing sand and gravel bars within the active channel and floodplain that have historically been dominated by cottonwood (*Populus trichocarpa*) and willows (*Salix* spp). Known to significantly alter the successional trajectories of ecosystems in New Zealand and Britain, the impact of invasion by *Buddleja* on ecosystems of the Pacific Northwest has not been studied. This exploratory study will investigate the potential impacts of invasion by *Buddleja* on the geomorphology of channel landforms by 1) describing the distribution of *Buddleja* within the active riparian zone, and 2) comparing the contribution to channel roughness and soil shear strength among species. This study will be the first investigation into the geomorphological role of *Buddleja* and will lay a foundation for future research regarding the impacts of *Buddleja* invasion in riparian ecosystems.

Research Summary: Methods

The objective of this study was to 1) gain an understanding of the distribution of *Buddleja* within the active riparian zone, and 2) determine the potential impacts of invasion by *Buddleja* to channel geomorphology. In order to address these objectives, we posed the following 3 questions:

1. *Where is Buddleja establishing and persisting within the active riparian zone relative to elevation and substrate, and how do these patterns of distribution differ from those of co-establishing native pioneers Populus and Salix?*

2. *Does Buddleja contribute to greater channel roughness than Populus or Salix?*

3. *Do Buddleja roots contribute to greater bank stability than Populus or Salix roots?*

A field site was selected on the lower Tolt River in the vicinity of the Tolt River Natural Area located approximately 2 miles east of the City of Carnation in northeast King County at latitude 47°41'45", longitude 121°49'22". The study site is located on a gravel bar within the active channel. Most areas of the study site are associated with one of two distinct in-channel landforms: 1) a vegetated island and 2) a secondary channel that was historically the main channel until it was diverted to its present location by a series of large scale flood events in the mid-1990s.

Vegetation sampling

Elevation, substrate, characteristics of dominant woody vegetation, and distance from the main active channel were measured within 160 1.5m^2 quadrats (Appendix A). Sixteen transects were established perpendicular to the thalweg of the main active channel using a systematic random design. Transects began at the edge of the main active channel and terminated at the start of the first terrace. Quadrats were established at five meter intervals along the length of each transect. The first quadrat of each transect was located on the edge of the main active channel, which was defined as the point at which woody vegetation had persisted for at least one year.

Persistent vegetation

Stems measuring at least10cm in height were assumed to have persisted for at least one year. In each quadrat, the number, basal diameter, and height of persistent *Populus*, *Buddleja*, *Salix* ramets were measured. Basal diameter and height were measured for up to and including the five largest ramets of each species. Mean values for diameter and height were assumed to be mean values at the quadrat scale.

Seedlings

To investigate whether patterns in the observed distribution of persistent woody vegetation could be attributed to patterns in the distribution of seedling establishment, the presence of seedlings were noted in a subset of 35 established quadrats. Quadrats were randomly selected using a random number table.

D50 substrate classification

In order to infer the relative energy of the river during flood events at each sampling point, the median grain size of substrate within quadrats was estimated using Wolman pebble counts. Median particle size (D50) of the substrate in each quadrat was calculated and categorized as either sand (≤2mm), gravel (2-64mm), or cobble (≥64mm).

Elevation

Elevation above the thalweg of the main active channel was measured at each quadrat using an autolevel and stadia rod. For each quadrat, the stadia rod was placed in the corner proximal to the main active channel on the downstream edge, and elevation was measured to the nearest tenth of a foot.

Channel roughness

In order to investigate the relative contribution of *Buddleja*, *Populus*, and *Salix* plants to total channel roughness, the density of basal and crown shoots were compared among species. The cross-sectional area intersected by crown shoots and the cross-sectional area intersected by basal shoots were measured on twenty randomly selected ramets of each study species,. These densities were used to calculate species-specific crown:base ratios which were used to 1) compare branching patterns between species and 2) estimate the total density of crown shoots per m^2 for each species by multiplying the number of ramets in each quadrat by the crown:base ratio.

Root cohesion

The contribution of roots to soil shear strength was estimated using the soil-root reinforcement model developed by Wu (1979). This model has been widely used to estimate the contribution of roots to soil shear strength by assuming that root cohesion can be expressed as a cohesion term in the Mohr-Coulomb failure criterion which describes the shear strength of saturated soil as:

$$S = c_s + c_r + (\sigma - \mu_w) \tan\varphi$$

where S is the soil-root composite shear strength, c_s is the effective cohesion of the soil, c_r is the apparent cohesion provided by roots, σ is normal stress, μ_w is soil pore-water pressure, and φ is the effective internal angle of friction. After Gray (1982), Root cohesion for each species was estimated by

$$c_r = 1.15\ t_r$$

where t_r is the tensile strength of roots per unit area of soil.

The average tensile strength of roots per unit area of soil (tr) was estimated by

$$t_r = \sum t_i n_i a_i / A_w$$

where t_i is the tensile strength of roots in size class i (calculated using the midpoint diameter of class i), n_i is the number of roots in size class i, a_i is the cross-sectional area of roots in size class i (calculated using the midpoint diameter of size class i), and A_w is the area of the profile wall.

The number of roots for individual size classes (n_i) and the area of profile wall (A_w) were estimated using the profile-wall method. Six trenches were dug for each species and the diameter of all roots intersecting profile walls were categorized according to the following diameter classes: 0-1, 1-2, 2-3, 3-4, 4-5, 5-6, 6-7, 7-8, 8-9, and 9-10mm.

Tensile strength

The tensile strength of roots up to three millimeters was tested using an Instron Universal Testing Machine. Roots were debarked at the ends, wrapped around 5cm capstan-type clamps and secured to backing plates using spring clamps. A constant strain of .03mm/sec was applied until rupture occurred. Tests were considered valid only if roots broke within the gauge length. A total of 50 roots ≤3mm were tested successfully. Due to difficulties encountered testing roots in larger diameter classes, no successful tests were achieved for roots >3mm.

Tensile strength was calculated by dividing the peak load at rupture by the cross-sectional area of the root at the point of rupture. The average tensile strength of roots in each diameter class (t_i) was calculated using linear regression.

Root density

Root density was expressed both as the number of roots per m^2 and as the area occupied by roots per unit area of soil (root area ratio (RAR)). Root area ratio was estimated by:

$$A_r/A_w = \sum n_i a_i / A_w$$

where A_r is the sum of the cross-sectional area of roots intersecting the profile wall, A_w is the area of the profile wall, n_i is the number of roots in diameter class i, a_i is the average cross-sectional area of roots in diameter class i (calculated using class midpoints).

<u>Data analysis</u>

For all tests, alpha levels were set to 0.05, and test results were considered significant when P-values fell below this level.

For normally distributed data, differences between species were tested using one-way analysis of variance (ANOVA) to compare means. Correlations were tested using Pearson's simple linear correlations, and linear relationships were tested using simple linear regression. In the event of deviations from normality, data was log- transformed prior to analysis.

Kruskal-Wallis tests, the non-parametric equivalent to one-way ANOVA, were used to compare data with substantial deviations from normality and/or unequal variances. Binary logistic regression analyses were used to test relationships between elevation and/or substrate and the presence of persistent woody vegetation and/or seedlings.

Tensile strength models were estimated using the curve-fit function in SPSS.

Research Summary: Results

<u>Vegetation</u>

Persistent plants

For all three study species, the lowest proportion of persistent plants was present in areas of low elevation and highest proportions in areas of medium elevation. However, this pattern was most pronounced for *Buddleja* compared to *Populus* and *Salix*. Relationships between elevation and the presence of persistent plants were tested using binary logistic regression. For *Buddleja* and *Populus*, the odds of persistent plants being present increased significantly with increases in elevation.

For all three study species, the highest proportion of persistent plants were present on sand substrates. This pattern was most notable for *Salix.* Relationships between substrate size and the presence of persistent plants were tested using binary logistic regressions. No significant relationships were observed.

Considering the spatial distribution of persistent plants, *Buddleja* was confined to the middle portion of the site, confined to higher elevation and smaller substrate sizes that indicate these areas are exposed to relatively low shear stress. In contrast, *Populus* was present throughout all regions of the study site, although in the upstream portion of the site where large particle sizes indicate areas exposed to high shear stress, persistent *Populus* plants were confined to areas of high elevation.

Seedlings

Compared to the distribution of persistent plants, *Populus* and *Buddleja* seedlings were present in higher proportions in areas of low elevation; there were not enough *Salix* seedlings to perform analyses. Relationships between elevation and seedling presence were tested using binary logistic regression. No significant relationships were observed. Not enough substrate classes were captured during seedling sampling to perform analyses using substrate.

Channel Roughness

Although no significant difference in the number or density of basal shoots per ramet was found between species, *Buddleja* ramets had 90% more crown shoots per ramet than *Populus* and 43% more crown shoots per ramet than *Salix*. *Buddleja* crown shoots occupied approximately 100% greater cross-sectional area than *Populus* crown shoots per ramet and approximately 81% greater cross-sectional area than *Salix* crown shoots per ramet.

The crown:base ratio was also significantly higher for *Buddleja* compared to *Populus* or *Salix.* Per ramet, *Buddleja* crown shoots intersected approximately 170% more cross-sectional area than was intersected by *Populus* crown shoots and approximately 212% more cross-sectional area than was intercepted by *Salix* crown shoots for each unit of cross-sectional area intersected by basal shoots.

Total crown shoot density, expressed as cm^2/m^2 was significantly higher for *Buddleja* than for *Populus* or *Salix*. *Buddleja* crown shoots occupied approximately 370% greater area per m2 than either *Populus* or *Salix*.

Root cohesion

Root density

For all three study species, more than 99% of all roots observed measured ≤3mm in diameter. The greatest proportion of roots was found in the smallest diameter class (<1mm). Total root density (expressed as the number of roots/m^2) was greatest for *Salix*, followed by *Buddleja* and *Populus*. For roots less than 1mm, *Populus* had 48% fewer roots than *Salix* and 39% fewer roots than *Buddleja*. In the 1 to 2mm diameter class, *Populus* had 33% fewer roots than *Salix* and 26% fewer roots than *Buddleja*. One-way ANOVA comparisons of means did not detect any significant differences in root density between species, most likely due to very high variances.

Tensile strength

There was a strong, significant relationship between tensile strength and root diameter: as diameter increased, tensile strength declined. *Salix* roots were significantly stronger than either *Buddleja* or *Populus*. Considering the mean tensile strength of all diameter classes combined, *Salix* roots were approximately 47% stronger per unit area than *Buddleja* and 44% stronger per unit area than *Populus*.

Root cohesion

Although results suggest that root cohesion due to *Salix* roots was substantially higher compared to *Buddleja* and *Populus*, no significant differences in root cohesion were found between species. Considering all diameter classes combined, *Salix* roots contributed approximately 63% greater cohesion to soil shear strength than *Buddleja* and 168% greater cohesion than *Populus.*

Discussion

Differences in the distribution of persistent *Buddleja, Populus, and Salix* plants are most likely the result of species-specific differences in the ability to tolerate different hydrogeomorphological disturbance regimes once established. Failure to detect any significant correlation between elevation and the presence of seedlings suggests that significant correlations observed in the distribution of persistent plants throughout the site are the result of post-germination responses to environmental conditions.

It is possible that drought tolerance characteristic of *Buddleja* enables plants to persist in higher proportions than *Populus* and *Salix* at higher elevations. However, a more likely explanation is that compared to *Populus* and *Salix*, *Buddleja* appears to be less tolerant of conditions present at low elevations such as frequent and/or high intensity inundation. It is likely that *Buddleja* plants both lack mechanisms for tolerating long periods of inundation, and are susceptible to breakage in areas subject to high shear stress due to weak and brittle wood.

Populus appears to be moderately tolerant of both high intensity flooding, frequent inundation, and drought. *Populus* was found in significantly lower densities only in areas of very low elevation that are subjected to frequent periods of prolonged inundation. High densities of *Populus* were confined to areas of high elevation in areas subjected to very high intensity flooding, which suggests that exposure to high shear stress is somewhat limiting for this species.

A larger proportion of persistent *Salix* plants were observed at low elevations than *Buddleja* or *Populus* which suggests that *Salix* is either less tolerant to drought or more tolerant to frequent and/or intense inundation than the other two study species. Inferences regarding *Salix* must be made with caution due to its limited distribution throughout the study site.

<u>Potential impacts to geomorphology</u>

Inferences regarding root cohesion are extremely limited due to difficulties encountered sampling roots on gravel bars and testing roots greater than 3mm in diameter. However, previous studies have found that the contribution of roots to increasing soil shear strength is significantly correlated with increases in root density. Therefore, invasion by *Buddleja* is likely to 1) increase sedimentation rates by increasing overall channel roughness, and 2) increase the stability of channel landforms. Landforms that develop as a result of these processes could potentially lead to channel narrowing and changes to the successional trajectory of riparian forests. However, because *Buddleja* is primarily found at higher elevations, these impacts will likely only occur during very high flood events.

Future research

This investigation has led to several ideas for future research. First, an investigation into the mechanisms driving observed patterns of distribution of *Buddleja* on landforms within the active riparian zone would be beneficial. These investigations would include, but not be limited to: tolerance to inundation, tolerance to drought, and tolerance to various intensities of shear stress.

Knowing the potential impacts of *Buddleja* on channel dynamics due to above and below ground plant morphology will enable more targeted research on the impacts of *Buddleja* on channel migration. These investigations should include, but not be limited to 1) comparing channel erodibility in areas of the channel colonized by *Buddleja* to areas of the channel without *Buddleja* using rates of channel migration over time, and 2) an investigation into differences in sedimentation rates in areas of the channel colonized by *Buddleja* to areas of the channel where *Buddleja* is absent.

Benefits of research

This investigative study has resulted in a better understanding of the distribution of *Buddleja* within the active riparian zone, and suggested potential causes for observed patterns in distribution of this newly listed noxious weed. Understanding the tolerance of *Buddleja* to different hydrogeomorphological regimes may assist land managers in early detection and control of *Buddleja* in active riparian zones. In addition, the results of this study can be used to better inform the public regarding the ecological risks associated with the continued use of invasive varieties of *Buddleja*.

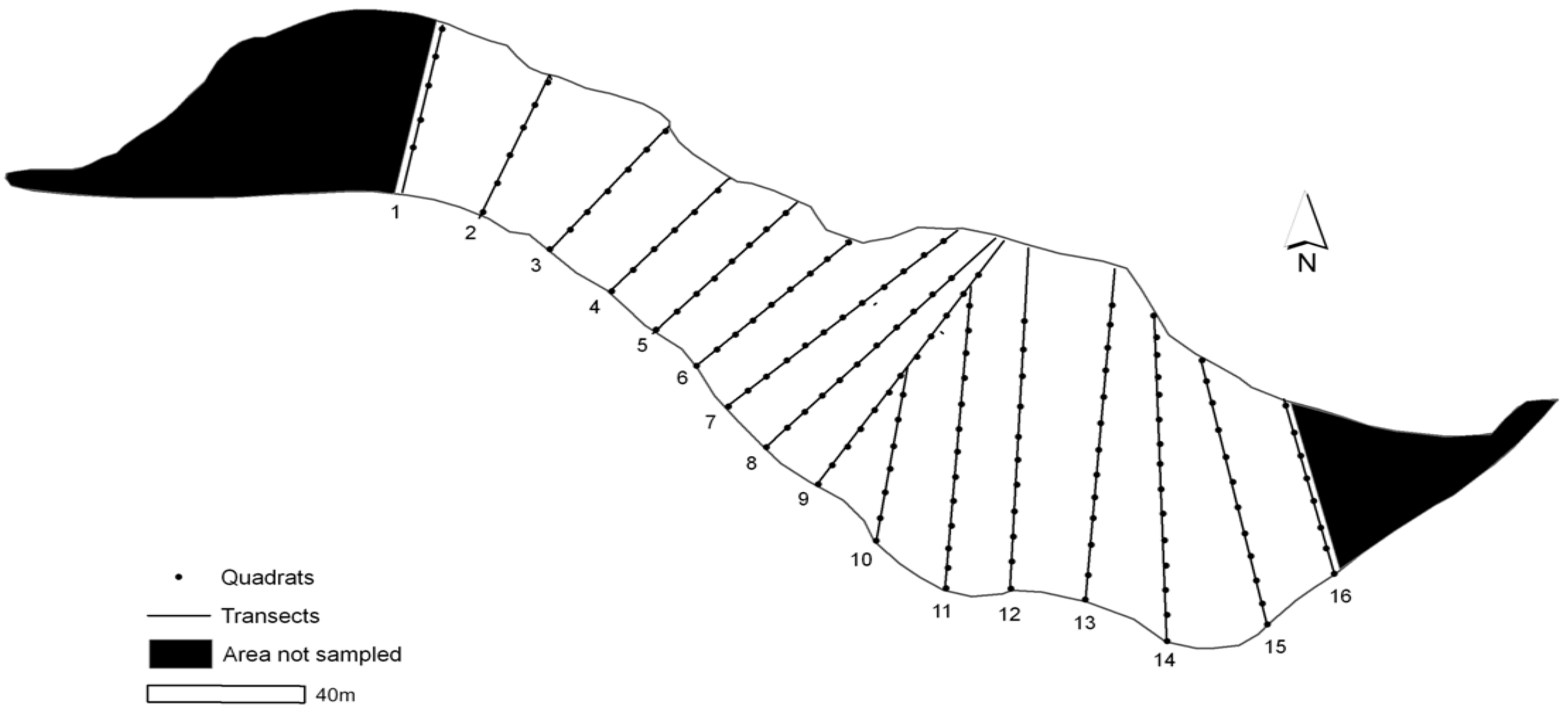
The primary researcher is currently completing her Masters' thesis with regards to this research. Funding from CIPM supported data collection during summer 2005; without funding, this project would have been severely limited in scope. The results of this research will be presented at a conference entitled 'Meeting the Challenge: Invasive Plants in PNW Ecosystems' at the University of Washington Botanic Garden's Center for Urban Horticulture in September 2006. In addition to a paper that will be published in the USDA Forest Service Pacific Northwest Research Station General Technical Report following the conference, we anticipate that this research will result in the publication of at least one peer-reviewed paper, and plan to submit work to specific journals in fall 2006. We will notify CIPM in the event that papers are accepted.

References cited

Wu, T.H., W.P. McKinnel III, and D.N. Swanston. 1979. Strength of tree roots and landslides on Prince of Wales Island, Alaska. Canadian Geotechnical Journal 16:19-33.

Gray, D.H. 1982. Biotechnical slope protection. Van Nostrand Reinhold Inc., New York, NY.

Appendix A



Study design for measuring elevation, substrate, and woody vegetation. Transects are numbered 1 – 16.

Appendix B

Budget

Item	Description	Cost ($)
Transportation	Mileage: $0.375/mi 200mi/wk for 12 weeks	900.00
Supplies	PVC pipe, rebar, flagging Xerox copies	100.00
Salary		3058.00
Benefits	Required by UW	358.00
Indirect costs	Required by UW	455.00
TOTAL		**4871.00**