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Urban Forest Restoration Cost Modeling: A Seattle Natural Areas Case Study

Jean M. Daniels, Weston Brinkley, and Michael D. Paruszkiewicz

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Authors

Jean M. Daniels is a research forester, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, 620 SW Main St., Suite 400, Portland, OR 97205; **Weston Brinkley** was the research and development program manager with Forterra, 901 5th Ave., Suite 2200, Seattle, WA 98164. Brinkley is currently principal and owner, Street Sounds Ecology, LLC, Seattle, WA; **Michael D. Paruszkiewicz** is an economist, Northwest Economic Research Center, Portland State University, Post Office Box 751, Portland, OR 97207.

Cover photographs: clockwise from top left—Forterra, EarthCorps Seattle, and Green Seattle Partnership.

Abstract

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Cities have become more committed to ecological restoration and management activities in urban natural areas. Data about costs are needed for better planning and reporting. The objective of this study is to estimate the costs for restoration activities in urban parks and green space in Seattle, Washington. Stewardship activity data were generated from a new database designed to track restoration efforts of the Green Seattle Partnership, an urban forest restoration group based in Seattle, Washington. Cost data were estimated and combined with activity data to arrive at per-acre costs for invasive removal, planting, monitoring, and trail work performed at restoration events between January 1, 2011, and June 30, 2013. Events where labor was performed by paid contractors were consistently the most costly, but the most productive in terms of acres treated per event. Cost modeling suggests that all else equal, event leader type and steep slopes contribute to greater costs, but costs decline with greater site size and phase of restoration. Limitations of the analysis as well as suggestions for improving restoration and cost data quality are discussed.

Keywords: Urban forestry, restoration costs, natural areas, Seattle, cost modeling.

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Introduction

Knowing the cost of restoring and maintaining urban forests and green space is essential for long-term planning and lasting conservation results. Forest restoration is a multimillion dollar annual activity across the Puget Sound region. Yet the costs of forest restoration in urban areas are not well understood, as the management and ecology of these areas are considerably different from traditional forest management. Additionally, urban forest restoration is completed by county and city governments as well as dozens of community groups and nonprofit organizations working as volunteers or on small budgets with little margin for cost overruns or unexpected expenses.

As restoration and management activities in urban natural areas have gained more support, the need to gather and provide treatment data to accurately report and predict costs has also increased. Holl and Howarth (2000) described issues surrounding funding restoration projects and identified the lack of cost reporting by restoration practitioners as a barrier. Cost data for specific projects are difficult to obtain and rarely reported in the literature. Without an adequate understanding of restoration costs, how can practitioners plan and budget for restoration activities?

Without an adequate understanding of restoration costs, how can practitioners plan and budget for restoration activities?

The city of Seattle defines urban forested natural areas as sections of urban parks, green belts, and other green spaces that contain a forested canopy and understory vegetation. These areas are particularly susceptible to degradation owing to their isolation from other natural areas and seed sources, and their proximity to human impacts. Of particular concern is the pervasiveness of invasive species and their displacement of native plants. Forest restoration is typically the physical activity required to manage these lands, including removal of invasive species and planting and maintenance of native plants.

The objective of this study is to estimate the costs for forest restoration activities in urban parks and green spaces in the Seattle area, and develop methodology that may be applied to urban forest restoration in the Pacific Northwest more broadly. The analysis combines a dataset of stewardship activities from 2.5 years of restoration events in Seattle with estimated hourly activity costs. Restoration activity data were generated from a new database designed and implemented to track restoration efforts of the Green Seattle Partnership (GSP), a partnership between Forterra, a regional conservation organization, the city of Seattle, and the stewardship community.

The city of Seattle manages over 6,200 ac of parks and natural areas within the city. Seattle parks are organized into subunits called park sites that have similar characteristics and management needs. Most parks contain multiple sites; for the purposes of this study, we considered the park site as the unit of analysis of restoration work.

Forest restoration work on park sites takes place during restoration events and could be conducted by paid city staff, paid contractors, or volunteers. Additionally, for some events, both volunteers and paid professionals work together. Costs associated with each of these event leaders differ, and all were considered in this analysis.

Forterra, the city, and other restoration partners would like to estimate the cost per acre to treat sites based on an initial site condition rating, restoration activity, and site characteristics. This link between restoration costs and the restoration activities occurring in city park sites has yet to be established. The hope is that combining costs with restoration accomplishments will lead to the development of a model to estimate the time and budget necessary to restore parks around the city. In addition, this information could increase the effectiveness and efficiency of restoration efforts, as it supports forecasting, realistic budget goals, and effective resource allocation, while providing valuable cost information to share among the urban restoration community. Steps involved include estimating restoration costs, compiling restoration activities and site characteristics, and constructing a cost model using common statistical techniques. Initially we looked to the literature for guidance on methods.

Literature Review

Little research has been published on the costs of urban ecological restoration in terrestrial systems, although the body of work regarding aquatic systems is growing (Kenney et al. 2012, Neal 2011). The following describes general approaches of cost accounting and modeling, then presents their application to ecological restoration efforts to analyze costs and (in a few cases) benefits of those efforts.

Cost accounting has long been important for the planning and design of development projects, whether public sector infrastructure, parks and recreation facilities, or commercial and residential developments.

Cost accounting has long been important for the planning and design of development projects, whether public sector infrastructure, parks and recreation facilities, or commercial and residential developments. The most common approach has been historical cost accounting, which are cost estimates based on past cost performance. In restoration, this method is commonly seen in bids for proposed projects or impact assessments of projected costs (LeBoon 2007, Palmer et al. 2007). Another method, cost engineering, is commonly used for planning and management for construction projects, particularly for estimating the costs of different project designs, materials selection, and labor requirements (Hendrickson 2008). Related efforts have focused on developing procedures, guides, and manuals that provide technical resources for estimating costs involved in permitting, designing, or constructing stream channel and bank stabilization and restoration projects (Pennsylvania Lake Management Society 2004, Templeton et al. 2008, U.S. Army Corps of Engineers 2005, Virginia Department of Conservation and Recreation 2004).

Only a few examples of restoration cost estimation and modeling are found in the literature. Bullock et al. (2011) described how the Economics of Ecosystems and Biodiversity project reviewed over 20,000 restoration case studies in 2011 and found only 96 studies providing meaningful costs data. Most represented aquatic ecosystems in landscapes such as the Willamette River basin (Michie 2010) in Oregon, the Wind River watershed in Washington state (Bair 2004, Wohl et al. 2005), and the Chesapeake Bay basin in Maryland (Center for Watershed Protection 2005). Costs analyses have also been conducted for fisheries management conservation plans (Snohomish County 2005) and oil spill response and damage costs (Etkin 2004). Related research examined the substitutability of wetlands mitigation for natural sites (Gutrich and Hitzhusen 2004) and the cost effectiveness of different strategies for restoring the vegetative cover and ecological functions of mangrove forests using a case study analyzing tradeoffs among actual costs and ecological outcomes (Lewis 2001).

Less information is available for terrestrial systems. Most studies have focused on invasive species (e.g., honeysuckle spread, Hartman and McCarthy 2004; tamarisk removal, Zavaleta 2000) and fire (e.g., ponderosa pine forest restoration, Lynch 2001, 2003; Macmillan et al. 1998). In one analysis, Zentner et al. (2003) estimated baseline costs for three types of wetland restoration costs (salt marsh, freshwater marsh, and riparian woodlands) and estimated that riparian woodland restoration costs for 1 ac totaled about $40,000.

A number of studies recommend full assessment of the benefits of restoration treatments as well as their costs. Stinchfield et al. (2008) discussed this literature as it relates to watershed restoration and salmon recovery in the Puget Sound area. Hurd (2009) assessed the analysis of costs and benefits in the broader context of the political economy of watershed restoration. Earlier, Zhao and Zilberman (1999) applied real option theory and the concepts of irreversibility and uncertainty to model restoration projects that may result in negative environmental benefits. Similarly, Ferraro (2004) applied a cost-efficiency framework to prioritize restoration treatments in the Chickasawhatchee Swamp in Georgia, emphasizing that decisionmakers need to consider costs as well as benefits when evaluating projects. Goldstein et al. (2008) also implicitly addressed benefits as well as costs with an approach that assessed the cost effectiveness of various restoration practices. They developed a general framework based on maximizing return-on-investment (ROI) then applied it to assess ROI profiles for potential projects to reforest montane pastureland in Hawaii, concluding that their approach could be applied to develop policies promoting more cost-effective restoration practices. De Groot et al. (2013) found that most restoration investments can achieve a rate of return of 10 percent for every dollar spent when benefits are assessed correctly.

Peer-reviewed literature provides some examples of cost models applied to restoration activities. However, published research is generally less applicable for projects in urban areas and provides little guidance for model development or comparable results.

Although reports of urban ecological restoration efforts are readily found in the peer-reviewed literature, research focusing on development of cost estimates for urban ecological restoration projects is rare (Neal 2004, Purcell et al. 2002). Daniels et al. (2014) estimated the cost of utilizing volunteers for restoration activities. Miller et al. (2009) applied optimization modeling to assess spatially explicit habitat acquisition and restoration strategies for 19 species of butterfly in a rapidly urbanizing county near Chicago, Illinois. They identified parcels in the immediate area that could be acquired and restored to provide habitat and then analyzed the tradeoffs between distance to sites, site acquisition, and restoration treatment costs.

In summary, peer-reviewed literature provides some examples of cost models applied to restoration activities. However, published research is generally less applicable for projects in urban areas and provides little guidance for model development or comparable results.

Data and Methods

The GSP would like to estimate the cost per acre to treat sites based on the following factors: initial site condition, restoration intensity, event leader, and physical characteristics. Each factor was believed to affect the cost of restoring any one site, and thus was a variable of interest for the cost model for urban forest restoration.

Steps involved include compiling restoration costs associated with each restoration phase, compiling site characteristics, and constructing a cost-per-acre model for all tree-iage categories. Developing a model was the focus of this work because of the wide applicability and practicality of models. Results may be generalizable to the greater restoration community, even though the analysis focuses on Seattle. Additionally, we undertook this work knowing that data limitations could be a challenge.

Tree-iage Prioritization System

The GSP prioritizes areas for restoration using a rapid assessment method developed by the city of Seattle called "tree-iage"

The GSP prioritizes areas for restoration using a rapid assessment method developed by the city of Seattle called "tree-iage" (Green Seattle Partnership 2005). This method has its origins in medical emergency situations where patients are treated according to severity of injury and the likelihood that intervention will be effective. The GSP has used this nine-part classification system for prioritizing restoration activities since 1999. Forested parks and open space are assigned a tree-iage classification level based on native tree canopy cover and composition, and degree of threat from invasive plants (fig. 1).

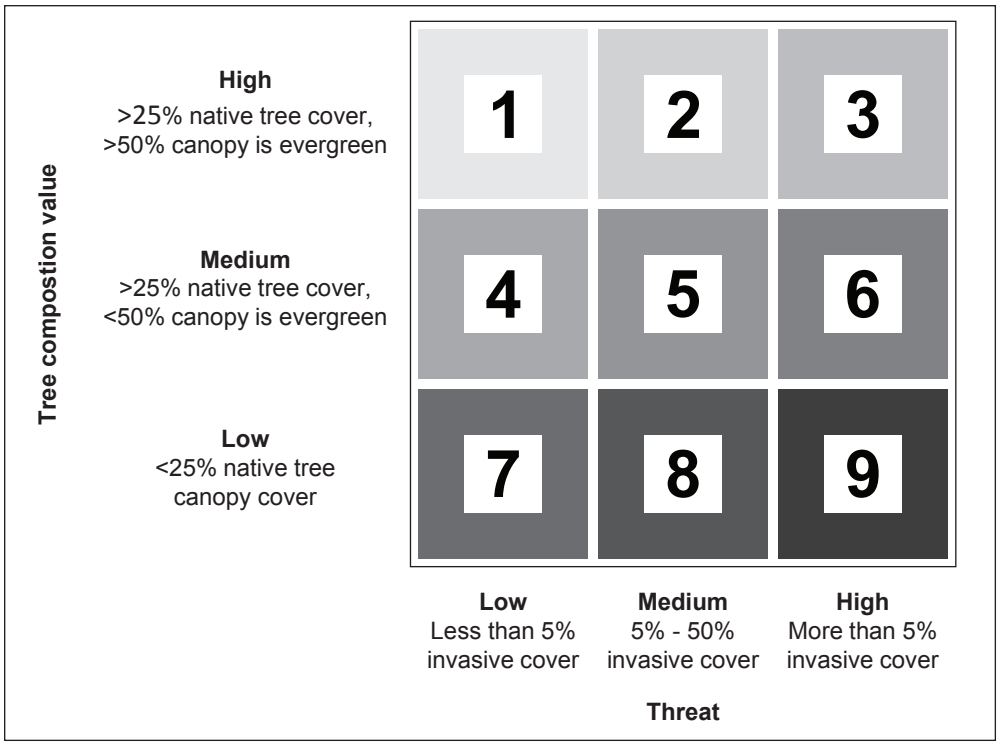

Figure 1—Tree-iage restoration prioritization categories (Green Seattle Partnership 2006).

Using this system, a site rated with a 1 would require the least effort to restore, as tree composition value is high and invasive threat is low. A site rated 9 would be the most difficult to restore, as it would likely be overrun with invasive plants with little tree canopy. Activities involving volunteers tend to concentrate most on planting and invasive plant removal in site classes 4, 5, 7, and 8. Sites with high invasive cover are more likely to require the skills of a paid contractor for herbicide application, heavy equipment operation, and erosion control, all of which has a direct impact on costs. The full cost of restoring a site based on its initial tree-iage classification is unknown, but all things equal, one would expect that restoration costs would increase with the intensity of the work required.

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Phases of Restoration

In addition to the tree-iage system, the GSP has developed a four-phase approach to scheduling restoration field work and categorizing activities. These phases are:

- Phase 1: invasive species removal
- Phase 2: planting of trees, shrubs, or ground cover
- Phase 3: secondary, or followup, invasive species removal
- Phase 4: long-term monitoring on restored sites
- Phase 5: trail maintenance

Trail maintenance is not a restoration activity per se, but trail activity data are collected so we include them here. We use the term treatment to describe any restoration activity, similarly to how it is used to describe wildland restoration. Treatments can occur during any of the four phases of forest restoration or trail maintenance work. Not all sites require all four phases; site conditions dictate which restoration activities are necessary. Although sites are assigned a tree-iage rating, budgeting for restoration work is done by phase. We expected that restoration costs would decrease as sites moved through the phases of work over time.

Event Leader Types

Green Seattle Partnership events are led by three possible leader types, and the leader type was hypothesized to affect treatment costs. Volunteer leaders were present at all-volunteer events, which were presumably the least expensive. Mixed volunteer-paid staff events, where paid staff supervised volunteers in restoration activities, were thought to be the next most expensive. Events using strictly paid contractors were likely the most expensive.

Physical Site Characteristics

Slope is an important consideration because volunteers were not allowed on slopes greater than 50 percent because of safety concerns.

Site size and steepness of terrain were hypothesized to affect treatment costs. The model variables slope and acres were added to account for these site-specific landscape factors. Slope is an important consideration because volunteers were not allowed on slopes greater than 50 percent because of safety concerns. Steep sites may also be much more costly for professional crews owing to the difficulty of working on the terrain. We wanted to test whether to expect a park site's size (in acres) to significantly affect restoration costs. Cases could be made for constant or increasing returns to scale for this type of work, meaning that the cost to treat a site could remain constant or decline for larger sites.

Restoration Data

The CEDAR database is used by staff, contractors, and volunteers to record information about sponsored restoration activities occurring in Seattle parks.

Forterra collects information for the GSP on restoration events using a proprietary database called the Centralized Data Repository (CEDAR). The CEDAR database is used by staff, contractors, and volunteers to record information about sponsored restoration activities occurring in Seattle parks. Restoration treatment data for events occurring between January 1, 2011, and June 30, 2013, were obtained from the CEDAR system. Parks in Seattle are divided into multiple sites for planning purposes, so we chose the site as the unit of analysis. For every event held, whether volunteer or contracted work was used, the date, park name, site name, and lead agency were used along with the count and hours of paid personnel and volunteers (youth and adult) present. Event duration was known, but only the total number of

people present at the park for the event was reported. So if the actual restoration work occurred across multiple sites in the same park, there was no way to directly measure how many hours were spent at each site. In such cases, hours were allocated using a weighted average of restoration activity to apportion total event time among sites and phases. The CEDAR data also included restoration work accomplished during each event. Multiple types of restoration could occur during the same event, including invasive removal, planting, watering, herbicide application, placement of cardboard and other weed blockers, and trail work. These activities were organized by phase, and events with multiple phases had hours assigned using a similar weighting process to allocate hours to sites. This study is the first to use restoration data from CEDAR for research purposes, which presented multiple challenges for our cost analysis.

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Tree-iage and Site Data

The tree-iage category, slope, and acreage of each park site were acquired from city of Seattle staff (Bazinet 2013). Some park sites were missing initial tree-iage categories. Because tree-iage is a key variable for the model, sites lacking tree-iage classification were not included, which meant 477 records (15 percent) were omitted. The remainder of the analysis was performed and results are reported only for sites with an initial tree-iage condition assessment. Table 1 shows the frequency that each tree-iage category appears in the dataset, which contained 2,668 observations.

Slope and acres of each park site were provided by the city of Seattle. Slope was measured in percentage of park site with slope greater than 50 percent. About 20 percent of sites treated had a significant amount of steep ground. The 50 percent slope was selected because safety concerns prohibit volunteers from working on steeper sites. The largest site was just over 19 ac, and the smallest was 0.04 ac, or 1,577 ft^2.

Table 1—Frequency distribution of each tree-iage category

Tree-iage	Frequency	Percent	Cumulative frequency	Cumulative percent
1	260	9.75	260	9.75
2	798	29.91	1,058	39.66
3	406	15.22	1,464	54.87
4	316	11.84	1,780	66.72
5	416	15.59	2,196	82.31
6	187	7.01	2,383	89.32
7	203	7.61	2,586	96.93
8	39	1.46	2,625	98.39
9	43	1.61	2,668	100.00

Estimating Restoration Costs

Costs were organized into six categories: labor and staff costs (counted as two categories), plants, materials, tools, and event preparation. These costs were estimated by site based on the recorded activity occurring during each restoration event. Total costs were divided by site acres to arrive at the cost per acre. The cost data were then combined with the treatment and site data to estimate the cost model. Next is a discussion of each cost and how it was calculated

Labor Costs

Labor costs included the wages of paid contractors and crews on site during restoration events.

Labor costs included the wages of paid contractors and crews on site during restoration events. They accrued during all phases of restoration. Hourly wage rates are listed in table 2; contractor names are not disclosed to protect privacy and proprietary wage information. Note that contractor 2 has two entries, an hourly labor rate for events without volunteers and a per-volunteer rate for leading mixed events with volunteers present.

The city of Seattle Park's Department crew on site during events was the Natural Area Crew (NAC), who also helped with event preparation (discussed later). Salaries for the city of Seattle employees are posted online (Bloom 2012). These include the salaries of the five NAC members, which were averaged to arrive at one hourly rate of $22.30. An average value was used because only the number of crew members and total hours spent onsite are included in CEDAR entries. Annual salary is converted to hourly wage by assuming 261 work days in a year.

Table 2—Labor costs for paid contractors

Labor information	Hourly rate ($)
Paid contractor 1	39.43
Paid contractor 2, no volunteers	32.31
Paid contractor 2, mixed events	34.67
Paid contractor 3	Actual invoiced value or 37.28
Paid contractor 4	40.00
Paid contractor 5	12.70

Staff Costs

Staff costs were the costs associated with professional staff in organizing, preparing, and followup after events—not conducting the physical restoration work in the forest. These costs were accrued for all phases by Forterra and city of Seattle staff for

time spent in support of restoration events. Not included were staff costs not directly related to the events themselves, such as planning, administration, and contracting.

In many cases, the CEDAR database contained the names of Seattle professional staff present at events. In these cases, actual salaries were used to estimate staff costs from the online source described above. Annual salaries ranged from $45,403 to $58,015, which corresponds to hourly wages of $21.74 to $27.78 again assuming 261 work days in a year. Staff costs for events where the individuals present were not identified were estimated based an average salary value of $22.30 per hour. A $50-hourly cost was assigned to all Forterra and other nongovernmental agency staff to reflect average salaries and overhead costs incurred by the organizations based on personal communication (Brinkley 2013).

Plant Costs

The number of plants by planting stock, including containers, bare root, plugs, and stakes was contained in the CEDAR data. Plant costs were estimated from two sources and were organized according to event-leader type: volunteer, mixed-leader, and paid contractor. First, we had to determine which individuals and groups actually received plants for volunteer and mixed-leader events. Eligible events were assigned per-plant prices based on expenditure data provided by Forterra: $2.50 for plants in gallon containers, $1.50 for bare root and plugs, and $0.50 for stakes. These prices were applied to all plant material from trees to understory ground cover. Paid contractor planting events were assigned plant costs either according to actual invoiced values or the Forterra prices described above when no invoice was available.

Materials Costs

These costs were provided directly in contractor bids and included things like fabric and coir logs purchased for erosion control. Only 15 events had materials costs listed in contractor invoices. Materials like gravel and wood chips were provided for free by the city for many events; crew time for delivery and distribution of materials was accounted for as a preparation cost.

Tool Costs

Tools were the most challenging cost to estimate and represent the greatest source of uncertainty. Forterra does not track the number of tools like shovels, rakes, and pruners they provide to support GSP volunteer events. In addition, the number and type of tools that Forterra and their community partners have in stock, purchase in a year, and provide for restoration events are all unknown. Because tool cost data are lacking, traditional methods for estimating tool costs could not be applied.

Tools were the most challenging cost to estimate and represent the greatest source of uncertainty.

Rather than exclude tool costs from the analysis, a valuation method was devised from conversations with Forterra staff.

First, a list of all possible tools was compiled from tool and materials request forms. An hourly rental rate for each tool was assigned based on an Internet search of rates advertised by rental companies in the Puget Sound area. Next, lists of tools typically used for restoration activities were developed only for phases 1, 2, 3, and trails (phase 5). We noted that tools provided to youth volunteers were different from those provided to adults, and adjusted the tool list accordingly. Then, for each restoration event, an average rental rate was computed and multiplied by the number of hours each volunteer spent there. An example for planting events appears in table 3. The decision about which events were assigned tool costs was made similarly to the distribution of plants described above. The resulting hourly and total tool costs are provided in table 4.

Preparation Costs

Events with preparation time were identified using information in the comments sections of the CEDAR database, which included crew time for delivering mulch, gravel, and burlap ahead of events. Time associated with staging and replanting

Table 3—Tool costs for adult and youth volunteers at planting (phase 2) events

Tool	Quantity	Volunteer type	Rental rate (dollars per hour)	Tool cost (dollars per hour per volunteer)
Gloves	Per volunteer	Youth and adult	2.50	2.50
Shovel (digging)	Per 3 volunteers	Youth and adult	7.33	2.44
Bucket	Per 6 volunteers	Youth and adult	5.00	0.83
Push broom	Per 6 volunteers	Adult	7.00	1.17
Wheelbarrow	Per 6 volunteers	Adult	14.33	2.39
			Adult hourly tool cost:	$9.33
			Youth hourly tool cost:	$5.78

Table 4—Hourly tool cost rates by phase summary table[a]

Volunteer type	Phase 1 (invasive removal)	Phase 2 (planting)	Phase 3 (followup invasive removal)	Phase 5 trails
Adult	$14.69	$9.33	$13.43	$5.53
Youth	$9.83	$5.78	$9.88	$2.50

[a] Note: no tools used in phase 4.

poorly planted plants before and after planting events was also included. Preparation costs differ from staff costs because they did not accrue during the events, but rather in support of events.

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The last step to prepare the data was to combine the restoration treatment data, site data, and cost estimates at the site level. After omitting events with zero costs or no tree-iage category, the site cost database contained 2,668 records. Descriptive statistics for the costs estimated for each restoration event are presented later in results. The dataset was entered into an economic model, which is described next.

The Economic Model

In economics, a model is a theoretical construct representing economic processes by a set of variables and the relationships between them. Fundamentally, a model is a simplified framework designed to illustrate a complex process. Empirical models are designed to be used with data to generate estimates for model variables using statistical techniques. Models are quite useful, in fact indispensable, in economic analysis, but they have limitations that can reduce their reliability. Models are based on assumptions that influence results, conclusions, and insights. If those initial assumptions are wrong, misleading, or incomplete, conclusions will be in error. Also, models are used because they provide a simplified version of reality, yet oversimplification can also lead to erroneous results. Selecting the wrong variables or omitting variables that should be in the model introduces error. Last, the quality of data for each variable will influence the quality of model results.

In this analysis, we developed an empirical model to estimate the cost per acre to restore natural area sites in Seattle. We assumed that this cost could be explained using the variables initial tree-iage rating, phase of restoration, event leader type (paid contractor, volunteer, or mix of the two), and the physical size and slope of the restoration site. Thus the empirical model estimated the per-acre cost to restore a site as a function of these five explanatory variables:

$$Ci = f(E, T, P, S, A)$$

where

i = the restoration site,
Ci = cost per acre to restore site i,
E = event leader type,
T = tree-iage rating,
P = phase of restoration,
S = site slope (percent), and
A = site size (acres).

In regression analysis, the left-hand side variable (C_i, above) is called the dependent variable and the set of variables on the right hand side of the equation are the independent variables. Regression analysis is a set of statistical techniques for estimating and modeling the relationship between a dependent variable and one or more independent variables. Initially, we estimated coefficients for the cost equation using a simple linear equation:

$$Ci = (\alpha + \beta_1 Ei + \beta_2 Ti + \beta_3 Pi + \beta_4 Si + \beta_5 Ai + \varepsilon),$$

where α is the intercept and ε is an error term, assumed to be identically and independently distributed. Once estimated, the beta coefficients β_i indicate the magnitude and direction of each variable's marginal effect on restoration cost, holding the other variables constant.

We identified a fixed-effects regression approach as the most appropriate for our model.

The structure of the dataset required modifying the initial regression model. Data were reorganized as a panel because they are longitudinal—meaning they track the same type of information on the same variable at multiple points in time. We identified a fixed-effects regression approach as the most appropriate for our model. Fixed-effects models control for the time-invariant characteristics in the longitudinal data to estimate the marginal effects of the independent variables on the dependent variable. Recall the tree-iage level of a site undergoing restoration does not change over time, so its expected relationship to the cost to restore that site is ambiguous. For instance, one could expect that a site with a tree-iage rating of six would correspond with a higher cost than a site rated with a one, given the labor-intensive work required to restore the site. But because the initial tree-iage rating was never updated, its relationship to the cost of restoring the site diminishes over time. However, there may be time-invariant characteristics associated with sites in a given tree-iage category that do correlate with the other independent variables—for instance, steep sites may be more likely to be assigned a higher tree-iage level because they are more difficult to maintain.

Ideally, our panel dataset would be balanced, with data covering each tree-iage equally over time. The panel dataset constructed here was unbalanced; sites within each tree-iage category were treated with irregular frequency over time, often over the course of varying numbers of events. An event's date was not a unique identifier of observations in the dataset as several events at different parks could occur on the same day. The resulting unbalanced panel thus has no time dimension; the fixed-effects model explains the variation in cost for sites that began at each tree-iage level.

The event leader data were categorical and entered the model as binary or dummy variables. In our case, we had three binary variables. Mathematically, only two of the three categories can appear in the estimation equation. We used volunteer-led events as the base for the equation and created dummy variables for mixed and paid events.

Algebraically, the fixed-effects model of the cost of treating site *i* and tree-iage level *j* is given by:

$$C_{ij} = \alpha + \beta_1 Paid_{ij} + \beta_2 Mixed_{ij} + \beta_3 Phase_{ij} + \beta_4 Steepness_{ij} + \beta_5 Size_{ij} + u_i + \varepsilon_{ij,}$$

where

C_{ij} = cost per acre of site i of initial tree-iage level *j*.

α = common intercept term.

$Paid_{ij}$ = binary variable; equals 1 if an event consisted of all paid labor.

Mixedij = binary variable; equals 1 if an event consisted of both paid and volunteer labor.

$Steepness_{ij}$ = the steepness of the event site, in percent greater than 50 percent slope.

$Size_{ij}$ = the size of the site, in acres.

u_i = tree-age rating fixed effect; site-invariant within a rating.

ε_{ij} = error term with usual assumptions.

General Results

Table 5 lists the restoration work accomplished at GSP events from January 1, 2011, to June 30, 2013, by phase and event leader type. Accomplishments were measured in different units, depending on the activity. The majority of work was performed by paid contractors in all categories except post restoration monitoring and trail maintenance. Most of the area treated was in restoration phase 3, followup weeding

The majority of work was performed by paid contractors in all categories except post restoration monitoring and trail maintenance.

Table 5—Restoration accomplishments by phase and event type

			Accomplishments by event-leader type		
Phase	**Treatment type**	**Treatment unit**	**Mixed**	**Contractor**	**Volunteer**
1	Invasives removed	Square feet	904,435	8,605,963	775,762
1	Survival rings	Count	389	505	1,320
1	Erosion control fabric	Square feet	300	119,908	3,285
1	Cut stumps	Count	45	29,265	0
1	Foliar herbicide	Square feet	0	513,096	0
2	Plants planted	Count	31,823	98,876	46,596
3	Weeding	Square feet	2,995,281	24,417,212	3,202,335
3	Cardboard	Square feet	140,755	272,786	110,663
3	Mulching	Square feet	521,297	850,419	585,815
3	Watering	Count	1,843	135,965	12,247
3	Erosion control fabric	Square feet	6,005	18,300	4,350
3	Cut stumps	Count	3,510	20,860	0
3	Foliar herbicide	Square feet	0	15,000	0
4	Monitoring plot	Count	118	29	8
5	Trail maintained	Feet	10,083	11,166	46,639
5	Trail structure	Count	336	168	74

and maintenance. Presumably, sites in phase 3 were better suited for volunteers than those in phase 1, but whether this is owing to site conditions or the nature of the work is unknown.

Restoration Costs

Overall, the total cost of 2.5 years of GSP-sponsored restoration events was calculated at just over $4 million, an average of about $540 per acre.

Labor, materials, staff, plants, preparation, and tool costs were calculated for each site (fig. 2). Labor represents the greatest restoration cost, followed by tools provided to volunteers. Materials and preparation time had little influence on costs. Overall, the total cost of 2.5 years of GSP-sponsored restoration events was calculated at just over $4 million, an average of about $540 per acre.

Table 6 shows descriptive statistics for the six categories of treatment costs, total costs, and costs per acre. Statistics were calculated after omitting zero values; there was no event that incurred every type of cost. Thus the count of the cost categories ranged from 13 to 2,339 while the total and average cost had 2,668 observations. Minimum and maximum values show wide variation in costs across sites. Note the standard deviation and gaps between the mean and median values for all cost categories. The average total cost and cost per acre for the entire sample of events and sites was $1,542 and $1,126, respectively. The mean cost for tools and labor was highest and similar at about $1,000, followed by plants with a mean of $475. Confidence intervals were calculated at the 95 percent significance level.

The greatest single cost was contracted labor, which was estimated at $1.7 million.

Table 7 shows treatment costs broken down by leader type: paid contractor, volunteer, and mixed leader. On average, paid contractor events were about six times more costly than volunteer-led events. The greatest single cost was contracted labor, which was estimated at $1.7 million. Plant costs were also greatest for paid contractors. Mixed events were the most costly; owing to wages for contractors and

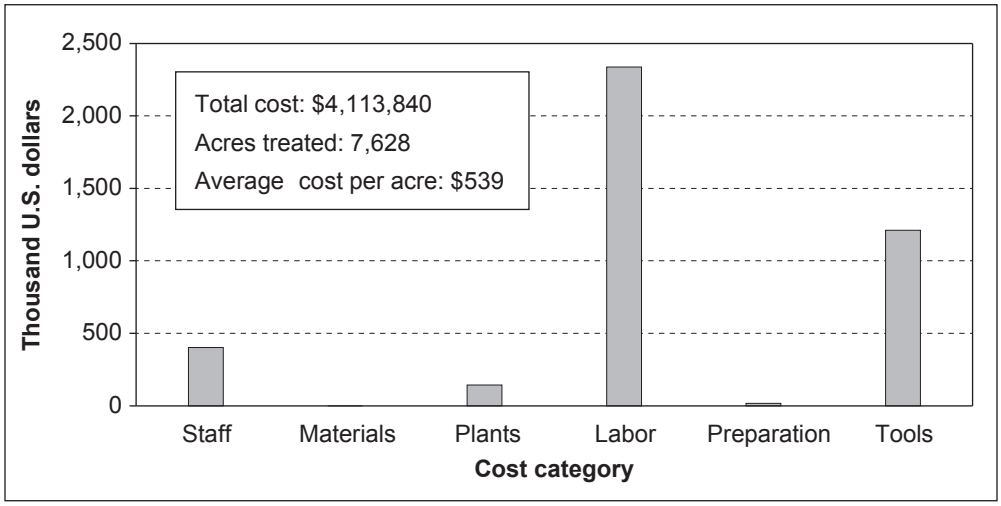

Figure 2—Total costs for Seattle parks restoration events held between January 1, 2011, and June 30, 2013.

Table 6—Descriptive statistics for estimated restoration costs

	Staff	Materials	Plants	Labor	Preparation	Tools	Total cost	Cost per acre
Calculations excluding zeroes:								
Count	545.00	13.00	303.00	2,339.00	72.00	1,212.00	2,668.00	2,668.00
Minimum	6.30	22.00	4.00	1.19	33.00	2.00	2.00	0.42
Maximum	7,331.06	264.00	9,125.00	40,412.38	3,489.00	13,083.00	40,412.38	37,394.22
Mean	738.86	71.54	475.07	999.53	241.04	999.21	1,541.92	1,126.60
Median	486.93	39.00	210.00	316.75	89.00	508.50	624.74	312.97
Standard deviation	853.97	70.74	969.79	2,125.08	457.04	1,428.78	2,663.87	2,473.77
Standard error	36.58	19.62	55.71	43.94	53.86	41.04	51.57	47.89
Sum	402,679.35	930.00	143,945.00	2,337,892.51	17,355.00	1,211,038.00	4,113,839.87	3,005,771.32
95% confidence interval	71.86	42.75	109.63	86.17	107.40	80.52	101.13	93.91

Table 7—Restoration costs by leader type at Green Seattle Partnership sponsored events from January 1, 2011, and June 30, 2013

Event leader type	Acres	Staff	Materials	Plants	Labor	Preparation	Tools	Total	Cost per acre
Mixed	3,769	348,229	0	64,428	635,044	741	1,097,782	2,146,224	569
Paid	2,792	54,450	930	69,814	1,702,848	16,614	0	1,844,657	661
Volunteer	1,068	0	0	9,703	0	0	113,256	122,959	115
Total	7,629	402,679	930	143,945	2,337,893	17,355	1,211,038	4,113,840	539

volunteer support staff and tool costs incurred for volunteers at particularly large events. At one particularly costly event, a paid staff of 20 was present to oversee 188 volunteers from a local corporation. Another mixed event had 17 paid contractors leading 179 adult and 24 youth volunteers. Preparation costs were mostly incurred by paid staff in support of restoration events.

Seattle Results

Restoration costs by site were combined with data obtained from the city of Seattle for each site's tree-iage rating, phase of restoration, acreage, and slope.

These next results largely pertain to the city of Seattle but could be generalizable to any city that uses a systematic approach to scheduling restoration and keeping records. Restoration costs by site were combined with data obtained from the city of Seattle for each site's tree-iage rating, phase of restoration, acreage, and slope. These costs can be highlighted in a variety of ways. Table 8 shows costs broken out by each of the five possible phases of work. Recall that phase 1 is invasive removal, phase 2 is planting, phase 3 is followup and maintenance, phase 4 is monitoring, and phase 5 is trail work. Most of the acres treated were in phase 3, meaning they already had invasive species removed and plantings established. Costs for phase 3 were the greatest for every cost category except plants, because of labor and staff costs for large mixed events and the tool costs associated with phase 3 volunteers.

Table 9 shows costs broken out by each of the nine possible tree-iage categories. Recall from figure 1 that tree-iage ratings combine invasive species threat with native tree canopy cover in a matrix of values that represent difficulty in restoring the site. Presumably, sites having fewer invasives and more tree canopy (rating of 1, 2, 3, 4, 5, and 7) would need less intensive restoration than sites rated 6, 8, and 9 with thick invasives and little tree canopy. Although total costs were greatest for sites in category 2, costs per acre are greatest for tree-iage category 1, followed by category 5. Category 3 had the most acres treated and the lowest cost per acre at $279. Acres in categories 8 and 9 sites were treated the least often, which makes sense as they are the most difficult sites to restore. Notice that most costs decline for tree-iage categories 6, 8, and 9, which likely reflects that few events are held on these sites, not that the sites are less expensive to restore.

Figure 3 shows restoration costs per acre by event leader and tree-iage rating. Overall, sites with a tree-iage rating of 9 treated by paid contractors were the most expensive at almost $1,800 per acre. In fact, per-acre costs were consistently greatest when only paid staff were working with one exception. Mixed-leader events were the most costly on tree-iage 1 and tree-iage 2 sites, with costs of $1,510 and $1,389 per acre respectively. Only tree-iage 2 sites were more expensive to restore using mixed-leader events, although per acre costs were similar to paid contractor costs for tree-iage 5 and 8. Volunteer-led events were the least expensive compared to other leaders, ranging from $115 per ac on sites rated tree-iage 3 to almost $450

Table 8—Restoration costs by phase of work at Green Seattle Partnership sponsored events from January 1, 2011, and June 30, 2013

Phase	Acres	Staff	Materials	Plants	Labor	Preparation	Tool	Total	Cost per acre
1	1,761	116,119	324	0	713,839	2,970	347,072	1,180,234	670
2	1,574	41,480	0	143,945	338,360	10,408	132,561	666,755	424
3	3,534	245,170	606	0	1,223,006	2,652	715,566	2,187,000	619
4	354	0	0	0	14,676	0	0	14,676	41
5	406	0	0	0	48,011	1,325	15,839	65,175	160
Total	7,629	402,679	930	143,945	2,337,893	17,355	1,211,038	4,113,840	539

Table 9—Restoration costs by tree-iage category at Green Seattle Partnership sponsored events from January 1, 2011, and June 30, 2013

Tree-iage category	Acres	Staff	Materials	Plants	Labor	Preparation	Tool	Total	Cost per acre
1	593	59,450	24	21,156	329,720	2,050	137,208	549,608	928
2	1,911	108,355	519	39,607	725,290	5,646	380,871	1,260,288	660
3	1,966	43,286	0	28,565	255,927	122	219,956	547,856	279
4	957	46,555	90	12,838	238,297	1,100	131,433	430,314	450
5	887	62,065	229	18,100	407,654	1,407	166,511	655,966	740
6	589	32,271	0	9,772	178,742	1,597	72,501	294,883	500
7	495	37,231	0	9,299	147,800	5,032	69,523	268,885	544
8	83	2,497	68	731	19,831	0	9,793	32,920	397
9	148	10,968	0	3,877	34,632	401	23,242	73,120	493
Total	7,629	402,679	930	143,945	2,337,893	17,355	1,211,038	4,113,840	539

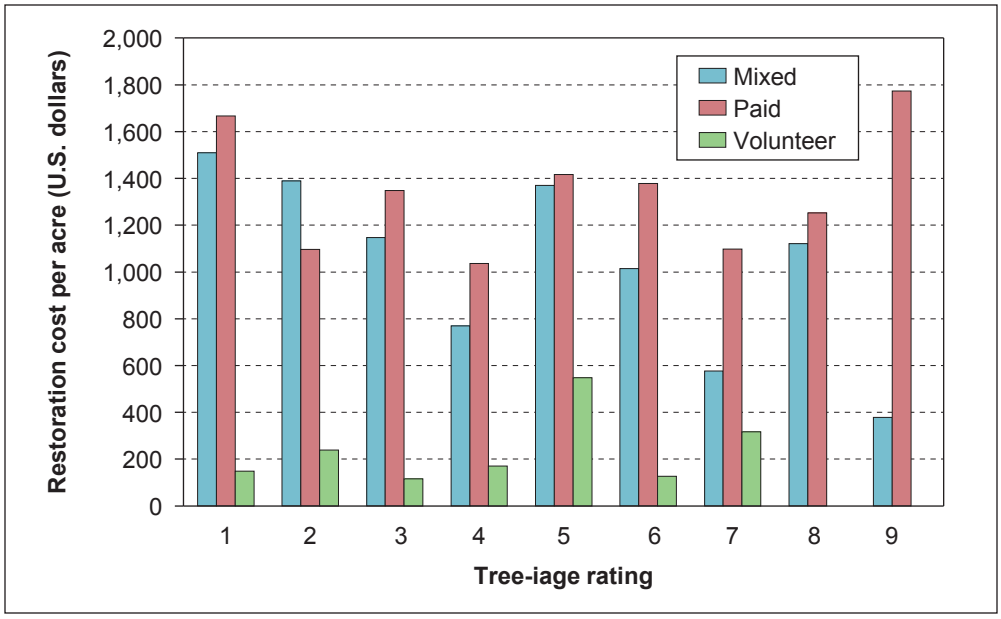

Figure 3—Restoration per-acre costs tree-iage category and event leader type.

per ac on sites rated tree-iage 5. Note that no volunteers were present at events on sites rated with an 8 or 9. Figure 3 suggests that costs per acre by tree-iage rapid assessment rating were not strongly related to the type of event leader.

The most expensive sites to restore were receiving followup maintenance (phase 3) after initially being assigned a tree-iage rating of 8.

Figure 4 shows average cost per acre by tree-iage category and phase of work. All tree-iage categories were undergoing some phase of work. The most expensive sites to restore were receiving followup maintenance (phase 3) after initially being assigned a tree-iage rating of 8. Sites in the easier to treat tree-iage categories incurred most of their costs in phase 1 (invasive plant removal). Phase 1 and phase 3 activities were the most costly. Presumably the costs observed for the most difficult to treat acres (tree-iage 6, 8, and 9) resulted from prohibiting the use of volunteers for restoration work on those sites.

Model Results

Recall that a fixed-effects specification was used for the regression model and that tree-iage rating was used as the longitudinal variable. The model performed best in log-linear form, so the cost-per-acre values of the dependent variable were transformed into their natural logarithms. This made the interpretation somewhat more complicated, but provided better results. Table 10 shows the model estimation output.

The key results from the estimation output can be briefly summarized. First, coefficients are statistically significant and estimates have the expected sign. This means that paid staff and terrain steepness add to an event's cost. The sign on the acreage variable is negative, reflecting an economy of scale as costs decline with larger sites. The phase coefficient is negative, which suggests that as sites progress

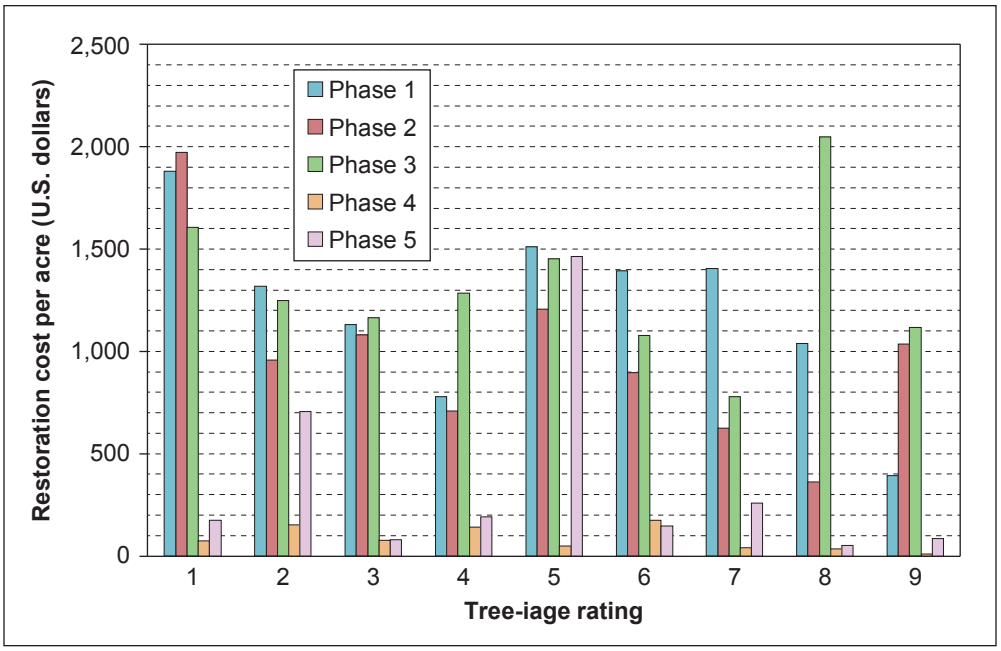

Figure 4—Restoration per-acre costs by tree-iage category and phase of work.

through the phases of restoration (or start from an advanced phase), the cost of the next event decreases. The F-test shows that the fixed effects (the unobserved characteristics of each tree-iage category) are jointly significant, verifying the validity of the chosen model form. Using the coefficients from the estimation output in table 10, the estimated cost equation can be written as:

$$\text{Natural log(cost per acre)} = 5.98 + 1.15\mathit{Paid} + 1.02\mathit{Mixed} - 0.31\mathit{Phase} + 0.52\mathit{Steepness} - 0.20_5\mathit{Size}$$

Table 10—Estimation results from the restoration cost-per-acre model

Variable	Coefficient	Standard error	P-value	95% confidence interval	
Intercept	5.989	0.135	0.000	5.725	6.253
Event type					
Mixed	1.017	0.113	0.000	0.796	1.239
Paid	1.152	0.116	0.000	0.925	1.380
Phase	-0.305	0.028	0.000	-0.360	-0.250
Acres	-0.196	0.009	0.000	-0.215	-0.178
Steep	0.523	0.132	0.000	0.263	0.782

R-squared: within = 0.2171
between = 0.3533
overall = 0.2294

F(8, 2636) = 6.51 Prob > F = 0.000

Interpreting the Model

Steepness had the greatest impact of the site variables; for every additional percentage of a site with slope greater than 50 percent, cost-per acre rose by about 50 percent.

The estimated coefficients in a log-linear equation are commonly interpreted as a percentage change in the dependent variable given a one-unit change in an independent variable, holding all else constant. These are called marginal impacts; for example, a 2-ac increase in size results in a 40 percent reduction in the per-acre cost to restore the site. Per-acre costs declined by 31 percent each time a site advances to the next phase of restoration. Steepness had the greatest impact of the site variables; for every additional percentage of a site with slope greater than 50 percent, cost-per acre rose by about 50 percent.

In contrast, the coefficients on the dummy variables (event types 2 and 3—mixed and paid staff, respectively) cannot be interpreted as percentage changes because of their discrete nature. Instead, the coefficient on say, the variable Paid contractors in the log-linear equation is interpreted as (100 X ($e^{(.1.152)}$ – 1), or 216 percent change in cost relative to the base case of an all-volunteer event.

Discussion

The objective of this analysis was to combine restoration activity data from a proprietary database with estimated site treatment costs to generate a cost-per-acre model for restoring forested urban green spaces in Seattle, Washington. Overall, the venture met with varying success.

General Findings

The large variation in the restoration cost estimates could be addressed by collapsing the data into fewer categories. The variables we selected were of particular interest to practitioners in the Seattle area. The majority of costs were incurred for four things: event preparation by professional staff, labor that physically performed the restoration work, tools, and plants. We believe these are the most basic treatment costs necessary to provide a defensible cost model; efforts to improve the data collected for these costs could pay off with improved results.

The lack of tool expenditure data was pervasive across multiple organizations that we approached once we ascertained that Forterra did not track tool purchases.

Tool costs were the most difficult to estimate and represent the greatest source of uncertainty in the cost estimates. The lack of tool expenditure data was pervasive across multiple organizations that we approached once we ascertained that Forterra did not track tool purchases. We spoke to organizations such as Friends of Trees, a Portland, Oregon, tree planting nonprofit and the Atlanta Tool Library, which stores, maintains, and loans tools for ecological restoration around Atlanta, Georgia. None of these organizations regularly inventory their tools, or could provide a definitive answer about how long a particular tool lasts or how often tools are replaced. One recommendation to improve the data for tools is to

decide how many of each tool to stock, count the tools in stock at the beginning of each year, and replace any missing or broken tools at one time and record the cost. At least, event leaders could record the number and type of tools provided at restoration events.

Costs by event-leader type were of particular interest and table 6 showed the majority of work was performed by paid contractors, followed by mixed- and volunteer-led events. Calculated values showed that sites treated by paid contractors cost an average of $1,490 per acre, but ranged from nearly $22,000 to $1.66 per acre. Mixed-leader events had the highest costs, largely owing to supervising staff wages and the cost of tools provided to volunteers. Costs per acre ranged from $24,000 to treat one steep site to $1.46, for planting five trees. Volunteer-led events were the least costly, averaging $435 per acre, but they tended to achieve the least in terms of restoration work performed per person. These events did, however, tend to draw participants from a variety of community partners; strong public participation may be one way to garner support for restoration work from municipal policymakers.

These events did, however, tend to draw participants from a variety of community partners; strong public participation may be one way to garner support for restoration work from municipal policymakers.

Seattle Area Findings

Sites in tree-iage categories 2, 5, and 7 were treated the most often. Figure 1 reveals that these sites vary with respect to native tree canopy cover, but all have a low to medium amount of invasive cover. These types of sites (along with category 1 and 4 sites) may be perceived as having a higher likelihood of restoration success. The selection of a site for restoration would ideally be determined by its initial tree-iage rating. Unfortunately, not all sites had been assigned a tree-iage category, and 15 percent of the data obtained from the CEDAR database had to be omitted from the analysis. Also, recall that tree-iage categories have never been updated to reflect work completed or restoration progress, so documenting success was problematic. For example, if $1,000 and 100 hours were spent removing invasive plants on a site in tree-iage category 5, unless the site was assigned an updated phase and tree-iage category afterwards, the cost to move between treatment categories cannot be determined. Two suggestions regarding the tree-iage rapid assessment system are to identify all sites lacking a tree-iage rating and assign them one and to periodically revise the tree-iage rating for sites that are undergoing restoration to reflect progress.

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More issues with the CEDAR data became apparent during our analysis. Hours of work occurring on multiple sites in the same park are not recorded separately, so apportioning hours worked among sites was challenging. Similarly, the total number of participants at each event was recorded, but restoration activities often occurred on multiple sites during the same event, with

no way to allocate the people among sites. In addition, there was no way to determine the proportion of a site that was treated during each event. One way to improve cost estimates is to record the number of participants by site rather than by event, but that could mean more work for event leaders, many of whom were volunteers.

Performance of the Model

In general, the accuracy or "fit" of a statistical model—such as the fixed-effects model described above—can be measured by the fraction of the dependent variable's variance that is explained by the independent variables. In our case, this refers to how much of the variation in cost per acre of restoration projects within each tree-iage level is explained by an event's phase, size, leadership type, and steepness of terrain.

The model's fit was modest. The "within" r-squared value in table 10 indicates that only 21 percent of the variation of cost per acre was explained by the model. In other words, most of that variation is owing to other factors that have not been identified. Nevertheless, the model does provide some useful information to event planners. Interpreted correctly, it gives a rough estimate of the marginal effect of any one variable, holding all others constant. It also strongly confirms the direction and significance of those effects—for instance, the addition of paid staff to an event's leadership adds a statistically significant amount to its cost per acre.

We tested the predictive ability of the cost equation by comparing the cost per acre predicted by the model against the actual cost of events at three sites selected from the dataset.

We tested the predictive ability of the cost equation by comparing the cost per acre predicted by the model against the actual cost of events at three sites selected from the dataset. The size of the discrepancy underlines the limitations of our results. Test site one held a planting event that occurred in the spring of 2011 in Pigeon Point Park at the Pigeon Point 04 site. The event was volunteer led, in phase 2 (planting) of restoration, and lasted 4 hours. One youth and seven adult volunteers installed 208 bareroot plants. The site had a tree-iage classification of 5 and contained 4.75 ac of relatively flat terrain as only 0.3 percent of the site is over 50 percent steep. Using these values, the model predicts the cost per acre of $257. Total estimated cost of treating the site was $428, a cost per acre of $90.

Test site two is the Rhododendron Trail in Frink Park, where a phase 3 weeding event occurred in the fall of 2011. The 3.5-hour event was mixed leader, with two paid staff supervising a volunteer pool of 26 adults and 2 youth as they weeded 15,000 ft^2 of ground. The site had a tree-iage classification of 6, contains 2.66 ac where 28 percent of the site is over 50 percent steep. Using these values,

the model predicts the cost per acre of $902. We estimated total cost of treating the site at that event was $2,938, a cost per acre of almost $1,109. The model performed best for this site.

Site three was also in Frink Park, at the 1.70-ac Upper Leschi site, at an event held in the spring of 2011. This phase 1-event was staffed by paid contractors, who removed 46,277 ft^2 of invasive plants, installed 800 ft^2 of erosion control fabric, and cut 600 undesirable trees. The site was quite difficult, with 70 percent of the site over 50 percent steep and an initial tree-iage rating of 6. Plugging these values into the model yields a cost per acre of $2,838. Total estimated cost of treating the site was $9,544, a cost per acre of $5,614.

Looking Ahead

By itself, the CEDAR database does not provide enough information to directly calculate the cost to complete a particular phase of restoration. Nor does it combine easily with tree-iage rapid assessment. The value in this work is its contribution to published literature on estimating urban forest and park restoration treatment and relative costs. The methods and results presented here depict the best possible results with the data given. The model was intended to be used by practitioners; findings may be generalizable if data limitations can be overcome.

Efforts to improve consistency and reliability in reporting among users would improve the usability of the data. The CEDAR system was new and training was ongoing, and initially its many users were entering data differently, which may have led to incomplete or inaccurate data (Brinkley 2013). We expect that data quality has improved over time. Data are likely to become more robust as training and additional experience will lead users of the CEDAR system to fill out more complete restoration logs. As the quality of the CEDAR data improves, this analysis and its methods may become a more powerful tool for predicting urban forest restoration costs.

Aside from tools, Forterra does track its own expenditures comprehensively and in detail, but their internal budgeting and accounting systems are decoupled from systems tracking site conditions, work completed, volunteer hours, and forest restoration accomplishments. Additionally, Forterra is one of many entities conducting forest restoration throughout Seattle and using the CEDAR system to record treatment activity. Building a viable bridge between existing financial accounting systems employed by municipalities and their partner organizations, and the restoration tracking systems on the ground could create a valuable tool to predict the costs associated with urban forest restoration.

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Metric Equivalents

When you know:	Multiply by:	To find:
Feet (ft)	0.305	Meters
Square feet (ft^2)	0.0929	Square meters
Acres (ac)	0.405	Hectares

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