RESEARCH ARTICLE

An Analysis of Factors Driving Success in Ecological Restoration Projects by a University-Community Partnership

Joy K. Wood, Warren G. Gold, James L. Fridley, Kern Ewing and Dev K. Niyogi

ABSTRACT

Every year since 2000, five to ten ecological restoration projects have been implemented on public and private lands in the Puget Sound region of Washington State by the University of Washington Restoration Ecology Network (UW-REN) capstone program. Students, faculty, and community partners have collaborated to implement these restoration projects, improve ecological function at the sites, and build site stewardship. Approximately twenty-nine, 2,000 m^2 projects from the first ten years of the capstone projects were retrospectively evaluated using a variety of response variables that could reflect ecological "success", including native species cover, richness, and diversity in the restoration plant community. We hypothesized that certain elements of restoration design and implementation, such as selected techniques for invasive vegetation management and the resulting degree of site stewardship, would strongly contribute to the success of these restoration projects. Stewardship was found to contribute to native species cover, richness, and diversity. Native plant species richness and diversity responded to initial invasive control techniques; stem-only removal did not work as well as root system removal for native species richness or diversity. The use of wood chip and cardboard-with-wood chip sheet mulches had less clear effects on species richness. An interaction between mulch and control technique was found to contribute to species diversity evenness. Overall, this study of restoration projects led by university students in cooperation with community partners highlights the importance of specific elements of restoration design and implementation and due diligence in the form of long-term stewardship.

Keywords: community-based learning, education in restoration, stewardship, students, urban restoration.

Restoration Recap

- This study surveyed outcomes of 29 design-build restoration projects conducted by teams of university students working with community organizations over a 10-year period. We found that university-community partnerships can make successful contributions to restoration needs while meeting academic goals if student-based projects include careful consideration and facilitation of the long-term maintenance needs of the site. Close attention should be paid to:
- Design elements that reduce maintenance requirements, such as the liberal application of wood chip mulch where needed to suppress invasive species and retain soil moisture in droughty environments.
- The thoroughness of site preparation so later stewardship needs are reduced, including removal of both above- and below-ground portions of invasive species where necessary and practical.
- Student engagement in building stewardship capacity in the surrounding community and provide clear aftercare guidelines to increase the likelihood of effective maintenance after the student projects have been completed.

The University of Washington Restoration Ecology Network (UW-REN) was established in the academic year 1999–2000 to develop integrated restoration experiences for university students from a variety of academic backgrounds. It was designed as a restoration-education partnership, facilitating local ecological restoration efforts while meeting educational goals for the students. The UW-REN capstone program allows students to work in

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multidisciplinary teams with community partners (e.g., local government, non-profit organization, private landowner) to restore damaged patches of landscapes in the Puget Sound basin of Washington State (Gold et al. 2006). The student restoration teams work with a community partner for eight months to develop site-specific goals and design a restoration project, implement the technical aspects of it, attempt to engage the surrounding community, and develop plans for on-going maintenance, enhancement, and monitoring in the form of stewardship (Peters et al. 2015, Smith et al. 2016). Initially, all sites are heavily invaded by non-native vegetation. Thus plans for restoration include the uniform goal to increase native plant cover and native plant diversity while managing invasive vegetation. Other goals in these restoration plans may be to enhance ecosystem function, establish or enhance community involvement, reduce erosion or stabilize slopes, promote succession, enhance or create wildlife habitat, and provide educational opportunities. The importance of site maintenance is also reflected in these goals: most restoration teams attempt to maintain an adjacent restoration site during the span of the program with at least one work party and to provide future maintenance plans for the community partner (Gold et al. 2006, Wood 2011).

Restoration of small-patch, fragmented urban open spaces can create habitat islands and corridors that increase the ecological health of the severed landscapes inherent in urban environments (Jackson et al. 2001, Sullivan et al. 2009, SER 2011, Oldfield et al. 2015). The long-term success of ecological restoration projects is critical to provide many ecosystem services such as stormwater and pollutant amelioration, nutrient cycling, productivity, carbon sequestration, decreasing urban heat island effects, noise reduction, habitat, recreation, and ground water recharge (Wood 2011, Clewell and Aronson 2013, Oldfield et al. 2015). Urban ecological restoration is often accomplished with the use of volunteers or students in many phases of projects, including design, implementation, monitoring, and maintenance (Gold et al. 2006). Maintenance and monitoring is important in any restoration. Without sustained maintenance of native plantings and invasive species removal for some period of time, ecological restoration rarely succeeds. Urban sites are particularly isolated from a natural landscape matrix where native vegetation spontaneously regenerates. As a result, urban sites are regularly invaded by ecologically harmful vegetation that inhibits the regeneration of native species (Walker and del Moral 2003, Hobbs et al. 2010, Clewell and Aronson 2013, Prach et al. 2015).

Monitoring the restoration trajectory and progress toward project goals guides management decisions and provides information for future projects (Palmer et al. 2007, Palmer et al. 2014). During the emergence of restoration as a science, and due to a lack of resources or planning, relatively few projects were monitored for an appropriate length of time, and often such assessments did not include data quantifying the site composition before restoration was implemented (Osenberg et al. 2006, Alexander and Allan 2007, Downs et al. 2011, Wortley et al. 2013). However, such circumstances should not preclude restorationists from evaluating and learning from these early restoration projects. There are few published models of upper-level student involvement that support multiple phases of a restoration project, and no critical analyses of the success of such student-based restoration efforts in urban areas (Gold et al. 2006, Hart et al. 2016). Here we present results on vegetation structure, native plant composition, and diversity from restorations in the UW-REN capstone project to better understand restoration practices within the program and inform other educational programs where students, community partners, and citizen volunteers intersect in the science of ecological restoration.

Methods

Site Selection

At the start of this project in the summer of 2009, restoration by UW-REN student teams had been on-going at 47 sites around the Puget Sound basin, Washington State, U.S. For this study, we chose sites based on their age since onsite restoration implementation, location, available documentation of techniques used, current access, and ecosystem type (Table 1). We studied forested wetland and upland ecosystems in the Puget Sound Trough Lowlands region. We focused on sites where restoration had been implemented for at least one year. So that we could examine mostly urban projects, the study was limited to sites that occurred within a 56-km radius of the UW-REN office at the University of Washington, Botanical Gardens in Seattle, Washington, USA (Figure 1). We omitted projects if we did not have complete documentation of the restoration techniques used in the project. Sites were also eliminated if access to the restoration site was not permitted by the land owner during the study period. To ensure meaningful ecological comparisons among sites, we chose only 29 sites in forested ecosystems from the remaining group of restoration sites, which were the most common ecosystem setting for the projects.

Field Measurements

We evaluated the plant communities at each restoration site using a regional vegetation monitoring protocol that was developed by Seattle Urban Nature (SUN) for use by the Green Seattle Partnership (Seattle Urban Nature 2009). SUN is now the Science Team at the Seattle-based non-profit organization, EarthCorps. We collected foliage cover measures using a 405-m^2 circular plot, with a diameter of 22.7 m. We chose sampling locations that best represented the implementation of restoration on each site. Precise pre-restoration data were not available.

Table 1. The restoration project sites in the Puget Sound basin, Washington State, US with factors and responses. Factors are level of stewardship (high or low), initial invasive vegetation control technique (above-ground or below-ground biomass removal), mulch application (use of cardboard beneath wood chips, wood chips only, or fabric), site age (young sites are one to three years old, and middle and mature sites are four to six, and seven to eight years old respectively. Responses include project metrics of native-plant percent cover (proportion of native vegetation), richness (number of species), and diversity (as the Shannon Index).

Site Name/Year Completed	Steward-ship Level	Initial Control Technique	Type of Mulch	Site Age	Ecosystem	Native Cover (%)	Native Richness	Native Diversity
Arboretum (2006)	Low	Below	Cardboard	Young	Wetland	57.81	25	2.15
Arboretum (2007)	Low	Below	Wood chips	Young	Wetland	49.58	14	1.82
Earth Sanctuary (2005)	High	Below	Cardboard	Middle	Upland	99.72	26	1.92
Earth Sanctuary (2006)	High	Below	Cardboard	Young	Upland	97.02	26	1.87
Earth Sanctuary (2008)	High	Below	Wood chips	Young	Upland	98.79	14	1.76
Evergreen (2001)	High	Below	Cardboard	Mature	Wetland	94.89	17	1.63
Fern Hollow (2001)	High	Below	Wood chips	Mature	Wetland	100.00	23	2.08
Frink Park (2002)	High	Below	Cardboard	Mature	Wetland	73.29	36	1.88
Grass Lawn Park (2003)	High	Below	Wood chips	Middle	Upland	42.23	11	1.95
Lawton Park (2002)	High	Below	Wood chips	Mature	Wetland	96.93	25	2.12
Licton Springs (2002)	High	Below	Cardboard	Mature	Wetland	78.55	18	2.24
Licton Springs (2004)	High	Below	Cardboard	Middle	Wetland	96.16	20	1.59
Licton Springs (2005)	High	Below	Cardboard	Middle	Wetland	76.24	18	2.08
Mosher Creek (2008)	Low	Below	Fabric	Young	Wetland	27.93	8	1.38
Rotary Park (2004)	Low	Below	Wood chips	Middle	Wetland	73.53	11	2.03
Swamp Creek (2005)	Low	Below	Cardboard	Middle	Upland	92.68	18	1.54
Swamp Creek (2006)	Low	Below	Cardboard	Young	Upland	54.78	21	1.95
Swamp Creek (2007)	Low	Below	Cardboard	Young	Upland	55.99	22	2.39
Thrasher's Corner (2002)	Low	Below	Wood chips	Mature	Upland	85.10	13	1.60
Union Bay Natural Area (UBNA, 2003)	Low	Above	Cardboard	Middle	Upland	9.30	6	1.74
UBNA (2004)	Low	Above	Wood chips	Middle	Upland	41.45	8	0.70
UBNA (2005)	Low	Above	Wood chips	Middle	Upland	87.35	11	1.48
UBNA (2006)	Low	Above	Wood chips	Young	Upland	37.48	8	1.78
W. Duwamish Greenbelt (WDG, 2004)	High	Below	Wood chips	Middle	Upland	85.86	15	1.76
WDG (2005)	High	Below	Wood chips	Middle	Upland	97.56	13	1.43
WDG (2006)	High	Below	Cardboard	Young	Upland	89.18	24	2.19
White Center (2008)	Low	Below	Fabric	Young	Upland	52.02	17	1.57
Yesler Creek (2007)	High	Below	Cardboard	Young	Wetland	83.14	24	2.03
Yesler Creek (2008)	High	Below	Cardboard	Young	Wetland	94.40	19	1.72

The estimated cover of all plant species occurring in each quadrat was collected to the nearest 1%, and species that were present in trace amounts were given a value of 0.1% cover. If multiple layers of vegetation were present (e.g., overstory and ground cover), they were both counted in the cover estimate; thus, most sites had greater than 100% total cover (Seattle Urban Nature 2009).

Project Factors

We chose a certain set of measures from the project documentation that could influence project outcomes (Table 1). The qualitative degree of stewardship for each project was assessed from an examination of the stewardship plan developed by the student team, and from an interview with each community partner to gauge its actual implementation. Sites were determined to have a "high" value of stewardship if they were associated with a community group that guarded and maintained the site regularly, which we defined as at least once per year beyond the first year of restoration. "Low" stewardship value was assigned to those sites that did not have any dedicated stewards or were maintained less frequently than once per year by any entity. Initial control technique refers to the method used to remove invasive vegetation, where "below" ground indicates removal of both the stems and roots, and "above" ground refers to stem removal only. The application of various mulch techniques was examined. "Cardboard" indicates that a layer of corrugated cardboard was installed underneath wood chip mulch. "Wood chips" refers to the use of a plain layer of wood chip mulch, and "fabric"

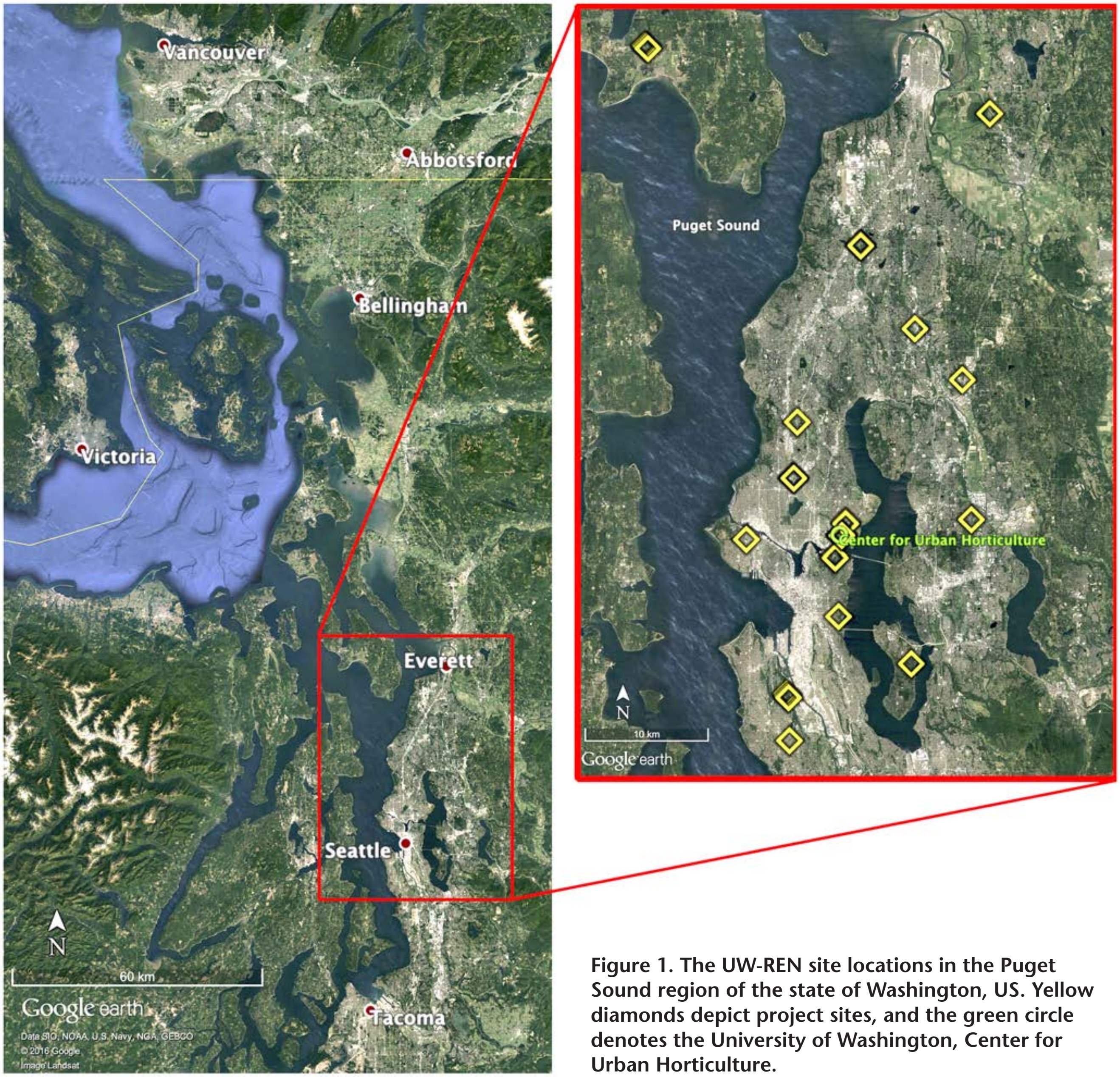

Figure 1. The UW-REN site locations in the Puget Sound region of the state of Washington, US. Yellow diamonds depict project sites, and the green circle denotes the University of Washington, Center for Urban Horticulture.

refers to covering much of the site in landscape fabric. We also studied time elapsed since the implementation of restoration and separated it into three age categories so that it could be included in the multivariate analysis: "Young" indicates that the site has been in restoration for one to three years since the capstone students completed their portion of the project, while "middle" and "mature" indicate four to six, and seven to eight years, respectively. Finally, we analyzed "wetland" versus "upland" forested ecosystems.

Data Analysis

We analyzed the explanatory categorical variables with interaction terms using R software (R: A Language and Environment for Statistical Computing, v 3.1.1, R Foundation for Statistical Computing, Vienna Austria). The ecosystem, wetland or upland, is not a manageable project factor, so it was analyzed separately.

We conducted permutational analysis of variance (PERMANOVA) tests on Bray-Curtis distance measures of raw cover data to evaluate effects of the explanatory variables on native plant cover, using "adonis" from the R package, "vegan" A double standardization was performed on the raw data, in which sites were relativized by site totals, and species by species maxima, using the "wisconsin" command, also from the "vegan" package. We determined species richness and Shannon Index diversity measures (Magurran 1988, Whittaker 2010) with the "specnumber" and "diversity" commands from "vegan." We then ran PERMANONA with Euclidian distance measures to determine the significance of study factors (Anderson 2001, McArdle and Anderson 2001, McCune and Grace 2002).

Table 2. Permutational analysis of the variance (PERMANOVA) results of the stewardship, control, mulch, restoration age, and ecosystem type on species cover, richness, and diversity of restorations in the Puget Sound basin, Washington State, US.

Species Cover	df	SS	MS	Pseudo-F	*p* (perm)
Stewardship	1	0.6318	0.63179	1.88690	0.001*
Control	1	0.4523	0.45227	1.35075	0.059
Mulch	2	0.8363	0.41815	1.24885	0.055
Age	2	0.8273	0.41366	1.23543	0.082
Stewardship × Mulch	1	0.4678	0.46778	1.39706	0.067
Stewardship × Age	2	0.8049	0.40243	1.20188	0.090
Control × Mulch	1	0.3374	0.33737	1.00759	0.460
Control × Age	1	0.4364	0.43643	1.30343	0.071
Mulch × Age	2	0.6650	0.33250	0.99303	0.482
Residuals	15	5.0224	0.33483	—	—
Total	28	10.4815	—	—	—
Ecosystem Type	1	0.5553	0.55527	1.51040	0.019*
Residuals	27	9.9263	0.36764	—	—
Total	28	10.4815	—	—	—
Species Richness	**df**	**SS**	**MS**	**Pseudo-F**	***p* (perm)**
Stewardship	1	317.55	317.55	13.339	0.003*
Control	1	197.47	197.47	8.295	0.008*
Mulch	2	256.92	128.46	5.396	0.017*
Age	2	86.19	43.10	1.810	0.184
Stewardship × Mulch	1	2.11	2.11	0.089	0.771
Stewardship × Age	2	22.97	11.48	0.482	0.640
Control × Mulch	1	29.87	29.87	1.255	0.272
Control × Age	1	29.95	29.95	1.258	0.262
Mulch × Age	2	63.12	31.56	1.326	0.293
Residuals	15	357.08	23.81	—	—
Total	28	1363.24	—	—	—
Ecosystem Type	1	127.80	127.80	2.793	0.108
Residuals	27	1235.40	45.76	—	—
Total	28	1363.20	—	—	—
Species Diversity	**df**	**SS**	**MS**	**Pseudo-F**	***p* (perm)**
Stewardship	1	0.2975	0.2975	5.2187	0.041*
Control	1	0.5595	0.5595	9.8140	0.011*
Mulch	2	0.3126	0.1563	2.7410	0.104
Age	2	0.2145	0.1072	1.8810	0.166
Stewardship × Mulch	1	0.0434	0.0434	0.7610	0.393
Stewardship × Age	2	0.3035	0.1518	2.6620	0.105
Control × Mulch	1	0.3455	0.3455	6.0600	0.036*
Control × Age	1	0.0616	0.0616	1.0800	0.279
Mulch × Age	2	0.1892	0.0946	1.6590	0.235
Residuals	15	0.8552	0.0570	—	—
Total	28	3.1823	—	—	—
Ecosystem Type	1	0.26	0.2600	2.4110	0.127
Residuals	27	2.92	0.1100	—	—
Total	28	3.18	—	—	—

We also utilized "vegan" packages for Non-metric Multidimensional Scaling (NMDS) (Oksanen et al. 2008, McCune and Grace 2002). We used "vegdist" to create distance measures of raw cover data. We ran stress tests to determine appropriate dimensions. Ultimately, we chose two dimensions with a stress level of nineteen (Clarke 1993, McCune and Grace 2002). To run the ordinations, we used Bray-Curtis distance measures with "metaMDS" for plant cover (McCune and Grace 2002). Additionally, we used 'envfit' to overlay the study factors onto the ordinations.

Results

Species Composition

We recorded 90 plant taxa at the UW-REN capstone project sites (Table 2). Seventy-two taxa were identified as Pacific Northwest, Puget Sound Lowland Trough native species. Five were neither native nor invasive species, and thirteen were invasive (King County 2014, UW 2014, WNPS 2014). We detected significant differences in how the project factors affected composition outcomes (Figure 2A). A high level of stewardship was associated with 32% greater native plant cover than low levels of stewardship (PERMANOVA, $p = 0.001$; Table 3). Forested wetland ecosystems were associated with 7% greater native cover than forested upland systems (PERMANOVA, $p = 0.019$).

The NMDS ordination on cover data demonstrated separation in ordinal space between sites with high and low stewardship (Figure 3). Also, it showed that two environmental variables, stewardship and initial control technique, were significantly correlated with the two NMDS axes. Stewardship was negatively correlated with both NMDS1 and NMDS2 (NMDS, $r^2 = 0.4892$, $p = 0.0004$), while initial control technique revealed a strong positive correlation with NMDS1, but was negatively correlated with NMDS2 (NMDS, $r^2 = 0.4830$, $p = 0.0001$).

Diversity Measures

Native plant species richness at the sites ranged from 6 to 36, and the Shannon Diversity Index ranged from 0.7 to 2.4 (Figures 2B and 2C). Level of stewardship, initial invasive plant control technique and mulch type had significant effects on plants species richness (PERMANOVA, $p = 0.003$, $p = 0.008$, and $p = 0.017$ respectively; Table 3), and had no significant interaction terms. Stewardship and removal of invasive species were associated with native plant diversity (PERMANOVA, $p = 0.041$ and $p = 0.011$ respectively). Also, there was a significant interaction between control and mulch techniques associated with diversity (PERMANOVA, $p = 0.036$).

Discussion

This study provides a retrospective look at a variety of restoration projects with their real myriad of differences in project design, restoration techniques, implementation, and stewardship resources. Before restoration, all sites were heavily covered by monocultures of invasive vegetation, particularly by the more common non-native invasive plant species in our region such as *Rubus armeniacus* (Himalayan blackberry), *Phalaris arundinacea* (reed canarygrass), and *Hedera helix* (English ivy). The UW-REN capstone students endeavored to enhance ecological function with native plants in small green spaces, utilizing a variety of site- and problem-specific design approaches as well as engaging surrounding communities to build long-term stewardship capacity. In this study, ecological outcomes were strongly influenced by the degree of site stewardship. Native plant species cover, richness, and diversity were all significantly greater in sites that had an associated site stewardship community. Stewards play a vital role in identifying the need for post-implementation restoration actions once the students have completed their portion of the project. Stewards usually care for installed plants (e.g., watering, protecting from herbivory), continue to remove invasive species, and perform site amelioration approaches (e.g., replenishing wood chip mulch as it degrades, adding more native species to increase diversity). The importance of site stewardship to restoration success is well documented in studies examining restoration from urban, rural, and wildland settings (Shandas and Messer 2008, Peters et al. 2015).

Native plant richness and diversity were also substantially influenced by the initial approach that student teams took in order to suppress non-native species. The UW-REN projects employed a suite of human-powered, non-chemical approaches, feasible for use by students and citizen volunteers. In the four sites where only above ground removal occurred, native plant diversity and cover were low, and the reappearance of invasive vegetation was high. In general, where student teams took a more aggressive approach, removing all below ground root parts of invasive plants, the resulting post-restoration native plant species cover was higher, and richness and diversity were significantly higher, revealing that such diligence at the onset of restoration is worth the time and effort.

Reasons to use a generous amount of mulch in ecological restorations are well documented (Chalker-Scott 2007). However, there are many forms of mulch with differing effects in specific environmental contexts. To improve project ecological outcomes, students include mulch techniques as part of their protocols, but it does not necessitate the use of additional cardboard. The application of cardboard mulch was significantly associated with greater species richness, but the use of cardboard under wood chip sheet mulch did not significantly improve native vegetation cover. We detected an interaction term for species diversity between mulch technique and invasive plant removal, highlighting the need for complete initial removal of invasive vegetation and continuous mulch treatment. Additionally, the use of coarse wood chips, either alone or with the addition of a cardboard layer, positively affected the development of native plant cover, richness, and diversity. However, since using cardboard did not result in significantly greater suppression of non-native vegetation, we strongly caution against drawing a causal link between the use of cardboard and enhanced species richness. Significantly greater native richness, but not diversity, is likely a spurious result of differing initial restoration design factors, such as the installation of a greater richness of species that was not assessed as part of this study. Finally, mulching is an element of urban restoration that can span

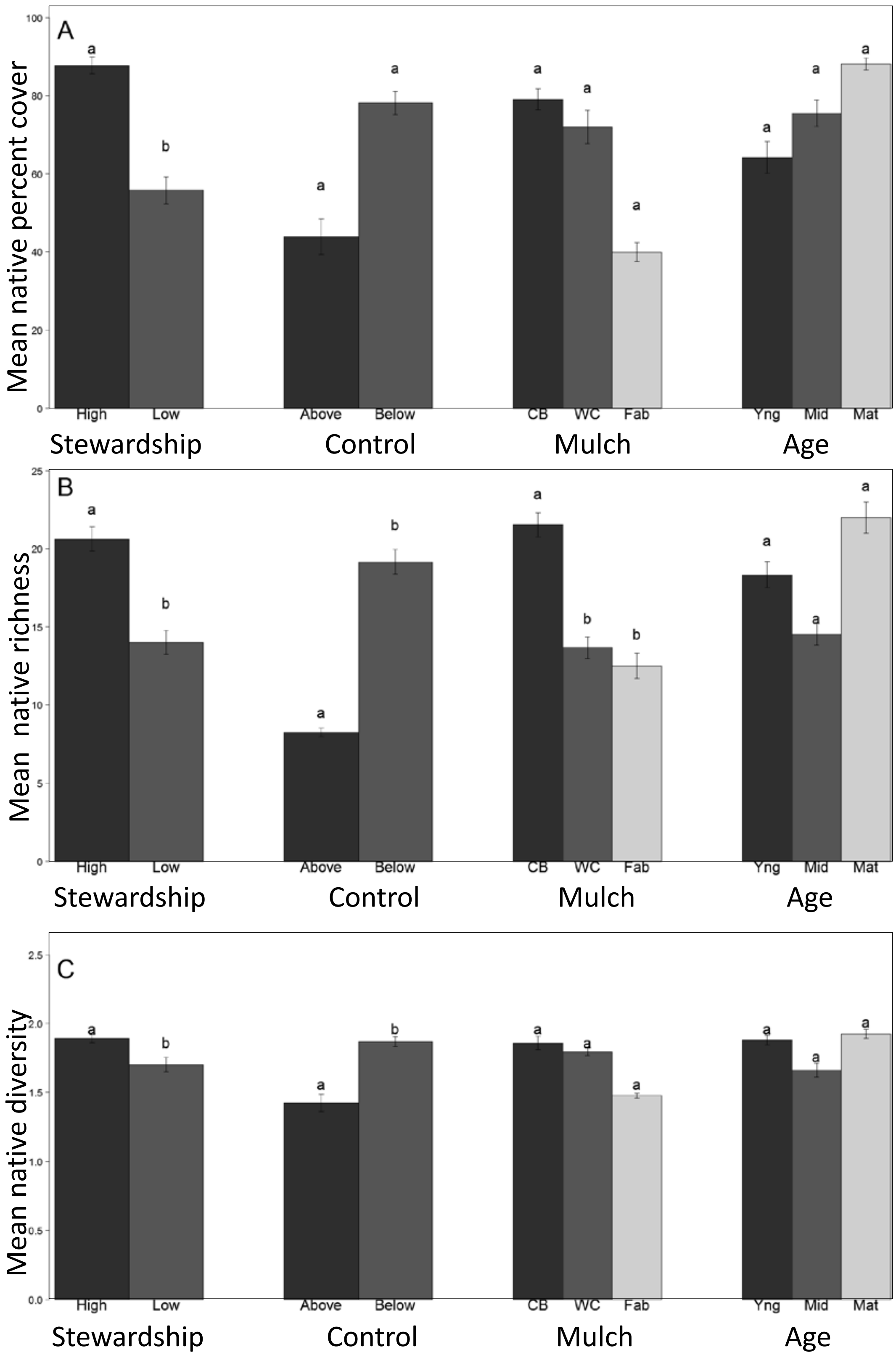

Figure 2: A) Mean native species cover responses (± SE) for level of stewardship (high or low), initial invasive-control technique (aboveground or belowground biomass), mulch technique (CDB denotes the application of cardboard beneath wood chips, WC stands for wood chips only, and Fab is for the application of fabric), and age category (young, middle, and mature). B) Mean native plant diversity (± S.E.) using richness and C) the Shannon Diversity Index (± S.E.) for all project factors in this study. An interaction term between control and mulch was also detected in diversity. Lower case letters indicate significant differences (*p* < 0.05) among treatments within the same group.

Table 3: Vegetation, growth habit, and native plant status in restorations in the Puget Sound basin, Washington State, US.

Habit	Scientific Name	Habit	Scientific Name	Habit	Scientific Name
Native Trees	*Abies grandis*	Native Shrubs cont'd	*Philadelphus lewisii*	Native Herbaceous cont'd	*Oplopanax horridus*
	Acer macrophyllum		*Physocarpus capitatus*		*Oxalis oregana*
	Alnus rubra		*Ribes lacustre*		*Petasites frigidus*
	Arbutus menziesii		*Rosa* sp.		*Polystichum munitum*
	Cornus nuttallii		*Rubus leucodermis*		*Pteridium aquilinum*
	Crataegus douglasii		*Rubus parviflorus*		*Solidago canadensis*
	Frangula purshiana		*Rubus spectabilis*		*Stachys* sp.
	Fraxinus latifolia		*Rubus ursinus*		*Tellima grandiflora*
	Malus fusca		*Salix* sp.		*Tiarella trifoliata*
	Picea sitchensis		*Sambucus racemosa*		*Tolmiea menziesii*
	Pinus contorta		*Spiraea douglasii*		*Veronica americana*
	Pinus monticola		*Symphoricarpos albus*		*Viola* sp.
	Populus balsamifera		*Vaccinium ovatum*	Non-native	*Populus alba*
	Prunus emarginata		*Vaccinium parvifolium*		*Lapsana communis*
	Pseudotsuga menziesii	Native Herbaceous	*Achillea millefolium*		*Plantago lanceolata*
	Taxus brevifolia		*Adiantum aleuticum*		*Rumex* sp.
	Thuja plicata		*Athyrium filix-femina*		Unknown Lawn Grass
	Tsuga heterophylla		*Bidens cernua*	Invasive Species	*Crataegus monogyna*
Native Shrubs	*Acer circinatum*		*Blechnum spicant*		*Sorbus aucuparia*
	Amelanchier alnifolia		*Carex* sp.		*Cirsium* sp.
	Arctostaphylos uva-ursi		*Chamerion angustifolium*		*Prunus* sp.
	Cornus sericea		*Dicentra formosa*		*Rubus armeniacus*
	Corylus cornuta		*Dryopteris expansa*		*Rubus laciniatus*
	Gaultheria shallon		*Equisetum* sp.		*Convolvulus arvensis*
	Holodiscus discolor		*Galium* sp.		*Geranium robertianum*
	Lonicera involucrata		*Geum macrophyllum*		*Hedera helix*
	Mahonia aquifolium		*Lysichiton americanus*		*Hypochaeris radicata*
	Mahonia nervosa		*Maianthemum dilatatum*		*Ranunculus repens*
	Myrica gale		*Maianthemum racemosum*		*Solanum dulcamara*
	Oemleria cerasiformis		*Oenanthe sarmentosa*		*Phalaris arundinacea*

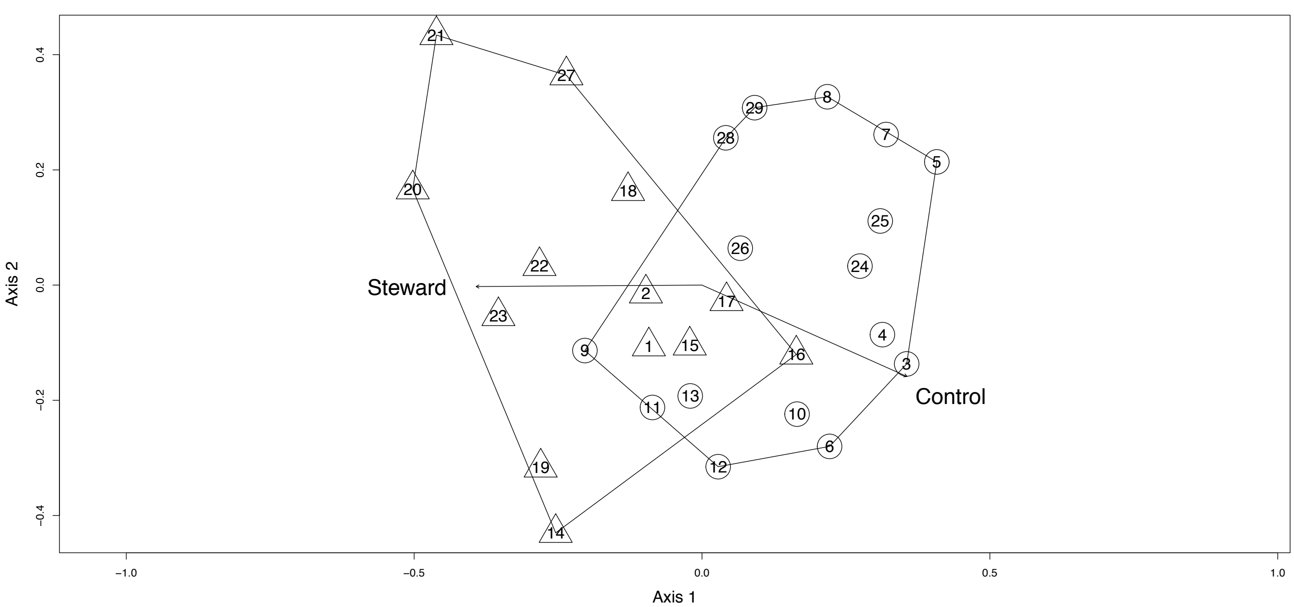

Figure 3: NMDS ordination of plant community cover data run on the Bray-Curtis distance matrix (k = 2). Numbers represent each project site, while circles indicate sites with high stewardship, and triangles indicate sites with low stewardship. Note the distinction in the convex hulls by level of stewardship. Arrows are significant factors (level of stewardship and initial control technique) overlaid upon the ordination.

the partnership, from students at project implementation to stewards going into the future.

This study examined the outcomes and lessons learned from one ecological restoration model that employs a university-community partnership in urban projects. The information gathered here may be used as baseline data for future quantitative studies at the same sites. Nonetheless, we were able to detect some broad-scale, important influences of selected project implementation and community engagement factors on measures of ecological success across these projects. In this study, the level of stewardship had the greatest impact on native species cover, richness, and diversity. Over time it appears that the proportional representation of non-native species is declining in these projects, with native species increasing from approximately 55% of the plant cover in young projects (1–3 years) to over 85% in older projects (7–8 years). We are confident that site stewardship plays a substantial role in this trend toward native-dominated plant cover. A major lesson from this study is the critical nature of setting up educational partnerships to include long-term stewardship of the sites, either by future students, community participants, or both. In this restoration model building stewardship capacity is now a recognized, major component of the student teams' academic responsibilities. While the students utilize their knowledge of ecology and other disciplines to implement restoration, on-going attention to site conditions from community stewards is clearly necessary for long-term success. Therefore, the students also become community organizers, educators, and outreach specialists, and they come away with a keen awareness of the important social context to ecological success in urban restoration. The UW-REN university-community partnership provides one model that can foster both student learning outcomes and positive ecological restoration outcomes, while cultivating strong ties within the community through engagement in the form of stewardship.

References

Alexander, G.G. and J.D. Allan. 2007. Ecological success in stream restoration: Case studies from the midwestern United States. *Environmental Management* 40:245–255.

Anderson, M.J. 2001. A new method for non-parametric multivariate analysis of variance. *Austral Ecology* 26:32–46.

Chalker-Scott, L., 2007. Viewpoint impact of mulches on landscape plants and the environment—A review. *Journal of Environmental Horticulture* 25:239–249.

Clarke, K.R., 1993. Non-parametric multivariate analysis of changes in community structure. *Australian Journal of Ecology* 18(206):117–143.

Clewell, A.F. and J. Aronson. 2013. *Ecological Restoration: Principles, Values, and Structure of an Emerging Profession*. Washington, D.C.: Island Press.

Downs, P.W., M.S. Singer, B.K. Orr, Z.E. Diggory and T.C. Church. 2011. Restoring ecological integrity in highly regulated rivers: The role of baseline data and analytical references. *Environmental Management* 48:847–864.

Gold, W., K. Ewing, J. Banks, M. Groom, T. Hinckley, D. Secord and D. Shebitz. 2006. Collaborative ecological restoration. *Science* 312:1880–1881.

Hart, D.D., J.A. Foley, L.E. Gilbert, L.J. Graumlich, A.R. Kapuscinski, J.G. Kramer, et al. 2016. Mobilizing the power of higher education to tackle the grand challenge of sustainability: Lessons from novel initiatives. *Elementa: Science of the Anthropocene,* doi:10.12952/journal.elementa.000090.

Hobbs, R.J., D.N. Cole, L. Yung, E.S. Zavaleta, G.H. Aplet, F.S. Chapin III, et al. 2010. Guiding concepts for park and wilderness stewardship in an era of global environmental change. *Frontiers in Ecology and the Environment* 8:483–490.

Jackson, R.B., S.R. Carpenter, C.N. Dahm, D.M. McKnight, R.J. Naiman, S.L. Postel and S.W. Running. 2001. Water in a changing world. *Ecological Applications* 11:1027–1045.

King County. 2014. Noxious Weeds, King County. www.kingcounty.gov/environment/animalsAndPlants/noxious-weeds/program-information.aspx.

Magurran, A.E., 1988. *Ecological Diversity and its Measurements*. Princeton, NJ: Princeton University Press.

McArdle, B.H. and M.J. Anderson. 2001. Fitting multivariate models to community data: A comment on distance-based redundancy analysis. *Ecology* 82:290–297.

McCune, B. and J.B. Grace. 2002. *Analysis of Ecological Communities*. Gleneden Beach, OR: MjM Software.

Oldfield, E.E., A.J. Felson, D.S.N. Auyeung, T.W. Crowther, N.F. Sonti, Y. Harada et al. 2015. Growing the urban forest: Tree performance in response to biotic and abiotic land management. *Restoration Ecology* 23:707–718.

Osenberg, C.W., B.M. Bolker, J.S. White, C.M. St. Mary and J.S. Shima. 2006. Statistical Issues and study design in ecological restorations: lessons learned from marine reserves. Pages 280–302 in D.A. Falk, M.A. Palmer and J.B. Zedler (eds), *Foundations of Restoration Ecology*. Washington, DC: Island Press.

Palmer, M.A., J.D. Allan, J. Meyer and E.S. Bernhardt. 2007. River restoration in the twenty-first century: Data and experiential knowledge to inform future efforts. *Restoration Ecology* 15: 472–481.

Palmer, M.A., Hondula, K.L. and B.J. Koch. 2014. Ecological restoration of streams and rivers: shifting strategies and shifting goals. *Annual Review of Ecology, Evolution, and Systematics*, 45: 247–272.

Peters, M.A., D. Hamilton and C. Eames. 2015. Action on the ground: A review of community environmental groups' restoration objectives, activities and partnerships in New Zealand. *New Zealand Journal of Ecology* 39:179–189.

Prach, K., A. Jírová, H. Dvoráková, P. Konvalinková and K. Rehounková. 2015. Do not neglect surroundings in restoration of disturbed sites. *Restoration Ecology* 23:310–314.

Seattle Urban Nature. 2009. Guidelines for SUN/GSP Vegetation Monitoring Protocols for Restoration Projects in Seattle Parks.

Society for Ecological Restoration (SER). 2011. Society for Ecological Restoration International (accessed January 1, 2011). www.ser.org.

Shandas, V. and W.B. Messer. 2008. Fostering green communities through civic engagement: community-based environmental stewardship in the Portland area. *Journal of the American Planning Association* 74:408–418.

Smith, R.F., R.J. Hawley, M.W. Neale, G.J. Vietz, E. Diaz-Pascacio, J. Herrmann, et al. 2016. Urban stream renovation: incorporating

societal objectives to achieve ecological improvements. *Freshwater Science* 35:364–379.
Sullivan, J.J., C. Meurk, K.J. Whaley and R. Simcock. 2009. Restoring native ecosystems in urban Auckland: Urban soils, isolation, and weeds as impediments to forest establishment. *New Zealand Journal of Ecology* 33:60–71.
University of Washington (UW). 2014. Consortium of Pacific Northwest Herbaria (accessed January 1, 2014). Burke Museum of Natural History and Culture. www.pnwherbaria.org/resources.php.
Walker, L.R. and R. del Moral. 2003. *Primary Succession and Ecosystem Rehabilitation.* Cambridge, UK: Cambridge University Press.
Whittaker, R.H. 2010. Evolution and Measurement of Species Diversity. *Taxon* 21:213–251.
Washington Native Plant Society. 2014. www.wnps.org.
Wood, J.K., 2011. Evaluating and monitoring the success of ecological restoration implemented by the University of Washington Restoration Ecology Network (UW-REN) capstone projects. MS thesis, University of Washington.
Wortley, L., J.M. Hero and M. Howes. 2013. Evaluating ecological restoration success: A review of the literature. *Restoration Ecology* 21:537–543.

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Hair cap moss. Bailey L.H. 1917. Standard Cyclopedia of Horticulture. New York, NY: The MacMillan Company. The Florida Center for Instructional Technology, fcit.usf.edu.