PERSPECTIVES

# The Rapid Riparian Revegetation Approach

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## ABSTRACT

Loss of native riparian vegetation and dominance of invasive species can have negative consequences for river and floodplain dynamics, trophic interactions, water quality, and riparian systems' ability to buffer some of the impacts of climate change. In response, restoration and enhancement efforts have increased in scope and scale in recent years, despite the fact that there is limited information on the effectiveness of techniques. This paper describes one approach to riparian restoration and enhancement, termed Rapid Riparian Revegetation (R3), which promotes rapid cover of woody plants in a composition designed to mimic reference site conditions. Limited peer-to-peer learning opportunities and the significant investment in time and resources required to document practices, monitor outcomes and disseminate findings hampers practitioners' ability to both systematically improve ecological restoration practices and to share lessons learned with broader audiences. This paper seeks to narrow this gap by describing in detail riparian revegetation project planning, management actions, and costs incurred within typical grant funded projects. Initial planting densities prescribed in this approach are typically in the range of 5,400 to 6,400 stems per hectare (approx. 2,200 to 2,600 per acre), with inter-planting in the second year at 1,300 to 1,600 stems per hectare (approx. 530 to 650 per acre). Most sites are established over six to seven years at a total cost of $11,000 to $20,000 per hectare (approx. $4,500 to $8,100 per acre). This approach evolved in and is tailored to Oregon's Willamette Basin, but principles and practices are applicable to other regions.


**Keywords:** Pacific Northwest, reforestation, restoration

The divide between restoration practice and science is frequently mentioned in the literature as a cause for concern (Lave 2009, Lave et al. 2010) and as a contributing factor to failure and inefficiency in restoration efforts (Wyborn et al. 2012). At the same time, evidence suggests that some local projects are in fact successful, indicating that practitioners possess insights that might be documented, studied, and replicated (Hobbs 2006, Reid et al. 2011). Obstacles to the integration of restoration science and practice include a "lack of collaboration, poor communication, inappropriate funding and political timelines, change inertia, and a lack of capacity" (Burbidge et al. 2011, p. 54). Restoration ecologists place significant emphasis on the need for improved monitoring and post-project appraisal (Kondolf 1995, Downs and Kondolf 2002), but we also recognize that restoration has largely relied upon the application of "ad-hoc methods" (Hobbs and Norton1996), which are seldom described in project records (Bernhardt et al. 2005). From a practitioner standpoint, this gap is equally critical to the assessment of restoration efficacy in terms of improving future practice. Here we support the need for increased information sharing between and among practitioners and wider audiences (Seavy et al. 2009), with particular attention to the documentation of practice.

Since 2000, some riparian restoration in Oregon's Willamette Basin has been implemented through an adaptive approach, termed Rapid Riparian Revegetation (R3), developed by restoration practitioners, contractors, and government staff in the Portland Metro region. This approach is geared towards the rapid establishment of diverse, resilient riparian forests, and has been applied to degraded and converted valley floor and foothill forestlands in urban, rural, and agricultural areas. Common site characteristics include high levels of invasive weed cover, significant anthropogenic influences on riparian systems, and fragmented and constricted riparian plant communities.

We provide a detailed description of the R3 approach, which is designed to increase the scope, scale, and effectiveness of riparian restoration by: 1) promoting the rapid transition of degraded riparian areas to those characterized by high diversity and function; and by 2) lowering the unit cost of revegetation through greater efficiency in implementation.

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## Background

Western Oregon's Willamette River Basin is home to over 33,750 kilometers of perennial streams and rivers and over 70 percent of the state's human population (Hulse et al. 2002, USGS 2012). Oregon's Department of Environmental Quality (DEQ) estimates that about 38,850 hectares, or 1.3 percent, of the Willamette Basin's land area currently requires restoration to protect water quality (Michie 2010). The Pacific coast has the largest concentration of river restoration projects in North America, driven by funding for habitat improvements to protect and enhance anadromous salmon populations (Bernhardt et al. 2005). The region's population is projected to nearly double by 2050, from 2 million to 3.9 million residents, leading to further extensive and intensive land uses that will likely increase the need for restoration (Hulse et al. 2002).

Decades of riparian planting projects in the Pacific Northwest have used practices drawn from the field of landscaping or from prescribed revegetation protocols such as those used in the Conservation Reserve Enhancement Program (CREP), in which plants, typically trees, are planted in wide spacing arrangements and maintained with plant tubing, mowing, herbicide application and irrigation until establishment. In the authors' experience, this approach, applied to sites with urban or agricultural soil disturbance and extensive competition from introduced species, rarely yields the diverse multilayer canopies and understory plant communities typical of healthy forests, and can create ideal conditions for colonization by invasive species.

We distinguish between practices grounded in a "landscaping" approach, and those that characterize the R3 approach, which is grounded in forestry and ecology. The "landscaping" approach was the predominant approach used in Willamette Basin throughout the 1990's and early 2000's, and examples range from small-scale voluntary riparian planting efforts to mitigation projects, to sites enrolled in riparian re-conversion programs such as CREP. Field evidence and programmatic assessments pointing to repeated revegetation failures (Anderson and Graziano 2002), and an expanding regulatory nexus with riparian shading as a water quality compliance tool for temperature management (Clean Water Services 2005), signaled the need for new approaches.

### *Theoretical Basis for R3 Approach*

One obstacle to the advancement of restoration is that practitioners often fail to apply or develop general theories or principles that in turn facilitate knowledge transfer across locations and contexts (Hobbs and Norton 1996). In an effort to counter this tendency, and in order to stimulate further discussion regarding the R3 approach, we articulate the key ecological concepts that guided its development.

### *Degraded Riparian Forests as Alternate Stable States*

Riparian forests are as spatially dynamic as the streams and rivers they border. Natural disturbance regimes shape species reproduction strategies and plant community composition, but edge effects, loss of linear connectivity, habitat homogeneity (Sudduth et al. 2011) and invasive species dominance (Fierke and Kauffman 2006) can constrain historic pathways of system recovery. In recognition of the need to address fundamental causes of ecosystem degradation, restoration ecologists have proposed a shift towards process-based restoration that "allows the system to respond to future perturbations through natural physical and biological adjustments, enabling riverine ecosystems to evolve and continue to function in response to shifting system drivers . . . [in contrast to] engineered solutions that create artificial and unnaturally static habitats" (Beechie et al. 2010, pp. 209–210). However, changes in biogeochemical cycling, shifts in trophic interactions, landscape discontinuity, and loss of native seed sources can cause plant communities to persist in degraded "alternate stable states" indefinitely (Suding et al. 2004).

While process-based strategies that remove fundamental barriers to natural regeneration are preferred and achievable in some contexts, we suggest there are also strong arguments in favor of active intervention to counter riparian degradation. Namely, the lack of financial, social, and political will to address root causes of system degradation (Lackey 2000), the reality that many degraded systems represent "resilient alternative states" that resist process-based restoration (Suding et al. 2004, p. 50), the spatial limits to seed dispersal, and temporal limits to seed viability that make active revegetation necessary in order to retain local genetic diversity (Broadhurst et al. 2008).

### *r/K Selection Analogy*

The ecological concept of r/K-selection (MacArthur and Wilson 1967) provides a useful analogy in contrasting R3 with other approaches to revegetation, with *r* representing the use of large numbers of small, bare-root plants established without plant tubes, mulch or irrigation (i.e., a reproductive strategy yielding a large number of offspring with limited individual parental investment), and with *K* representing the reliance on relatively few, large plants typically maintained with tubes, mulch and irrigation (i.e. a strategy involving few, large offspring with high parental investment). Examples of the latter are found throughout the Pacific Northwest and elsewhere (for examples, see Anderson and Graziano 2002, Butler and Long 2005) and are characterized by planting densities below 2,000 stems per hectare (approx. 800 per acre) and plant composition often more reflective of species availability, perceived reliability, landowner preference, or economic value than ecological objectives. Maintenance prescriptions on such sites often consist of periodic mowing for several years to prevent swamping by grasses, and projects are considered complete once funding ends or when plants no longer require irrigation. By contrast, the R3 approach aims to minimize the per-plant investment and to achieve rapid canopy cover through the use of relatively inexpensive bare-root seedlings installed in densities and compositions drawn from local reference sites as well as through efficient site layout and streamlined maintenance practices that are administered until site conditions meet a reference condition trajectory (typically 5–7 years from time of planting). The approach employs a high percentage of shrubs to establish 'trans-successional' assemblages that include the woody species expected to be present on site at all seral stages. Examples include common snowberry (*Symphoricarpos albus*), Pacific ninebark (*Physocarpus capitatus*), red Elderberry (*Sambucus racemosa*), red osier dogwood (*Cornus stolonifera*) and swamp rose (*Rosa pisocarpa*) among others, depending on site conditions.

## The R3 Approach

R3 is an adaptive approach to the restoration or enhancement of tree and shrub dominated riparian plant communities. Elements described in this paper range from site assessment to planting and include observed limiting factors to riparian restoration success, as well as strategies devised to help address them (Table 1). While the focus of this paper is the restoration and enhancement of degraded riparian forests, we acknowledge the critical importance of non-woody plant dominated riparian plant communities, including fluvial marshes, sloughs, wet meadows, alkali meadows and off-channel ephemeral ponds (Weisberg et al. 2012), and do not intend to imply that riparian forests are appropriate or desired in all contexts.

### *Evaluation of Site Dynamics*

The R3 approach draws on combinations of field observations, soil maps, wetland delineation data, topographic maps, and Laser Imaging Detection and Ranging (LiDAR) mapping of ground surface and site features (when available) to characterize site conditions. Flood events, prolonged periods of inundation or drought, groundwater interactions, sediment deposition and scour, lateral channel migration, herbivory, and other disturbance factors inform site layout and species selection. We use small seedlings (30–60 cm tall), which tend to have greater root to shoot ratios than larger nursery stock and are often better suited to riparian site conditions. Under the "landscaping" approach, site dynamics may also be considered but irrigation, soil amendments, plant stakes, tubing, and caging are often used to mitigate the risks and challenges posed by site conditions.

### *Reference Sites*

Reference sites identified in existing riparian forests with low levels of human disturbance and indicators of intact ecological processes can serve to inform desired future conditions at revegetation sites. However, in the context of climate change, invasive species introductions, and rapid urbanization, reference sites may be unavailable or difficult to find. Modeling approaches such as the dynamic reference concept (Hiers et al. 2012) attempt to accommodate such factors, but their data requirements and complexity places them out of reach of most practitioners.

While species composition in riparian planting projects is often derived from the palette of plants known by a designer or practitioner to tolerate site conditions, R3 uses a "guiding image" approach *sensu* Palmer et al. (2005) that incorporates local reference site data on species diversity, stem densities, tree to shrub ratios, non-native or invasive cover, and site constraints to anchor planting plans in an ecological context. This process is supported by continual reference site observations with attention to various stages of succession. In most cases, R3 planting plans are informed by two or more reference sites located at similar elevations to the project site within the same Fifth Field Hydrologic Unit Code (Sounhein 2003). R3 reference sites typically consist of non-planted, early- and mid-seral forest stands with no more than 20 percent non-native species cover in the canopy and sub-canopy layers. However, late-seral reference sites also provide valuable information that informs site planning. Because many factors determine the health and likely resiliency of a given forest and its suitability as a reference site, we collect data from plots selected preferentially with consideration given to factors such as stand age, species dominance, 'representativeness', distance from the edge, signs of disturbance, apparent resistance to invasion by certain weeds, and species richness. Within plots we count all live woody stems taller than 0.3 meters (1 foot) and count multi-stem species as one stem per 0.09 square meters (1 square foot).

Although there is significant variability among habitat types and successional stages, observations of native riparian forests in western Oregon (Table 2, N = 16) reveal densities ranging from 3,600 to 30,600 woody stems per hectare (approx. 1,400 to 12,400 per acre) with compositions averaging 21 percent trees and 79 percent shrubs (Query 2001, P. Guillozet, unpub. data). This is consistent with historic records such as land survey data from the late 1800's and early 1900's that describe the riparian forests as dense stands of vegetation with early successional species along active channels (Christy and Alverson 2011).

### *Establishment of Project Boundaries*

Existing and potential weed populations, poor management of adjacent lands, livestock impacts, and public uses can pose significant challenges to the establishment

**Table 1. Selected revegetation project elements, common limiting factors and the R3 approach.**

| Project Element | Limiting Factor | R3 Approach |
|---|---|---|
| Site dynamics | Lack of attention to disturbance regimes and ecological boundary conditions. High flows can wash away large nursery stock, plant protectors and irrigation systems. | Conduct detailed evaluation of site conditions. Select flood resistant stock sizes and avoid using plant protectors and irrigation systems. |
| Reference site data | Sites planted and managed out of context often revert to degraded alternate stable states. | Use reference site data as a 'guiding image' in the context of site conditions and surrounding land uses. |
| Site boundary establishment | Irregular or illogical site boundaries can increase unit costs and lead to reduced forest resilience. | Establish defensible ecological or physical boundaries to reduce edge effects. |
| Site preparation | Large equipment can disrupt soils and eliminate existing native vegetation. | Protect existing native vegetation through targeted chainsaw clearing and backpack herbicide application. |
| Ground cover establishment | Bare ground allows colonization by broadleaf weeds; tall grasses harbor voles and compete with plantings. | Seed with small-stature native grasses to establish effective cover without swamping plantings. |
| Species diversity | Species lists are often divorced from local plant communities. | Develop species lists informed by reference site diversity. |
| Tree to shrub ratios | Lack of appropriate vegetation layers (i.e. structural diversity) can facilitate invasion by weeds. | Distinguish between trees, arborescent shrubs, small shrubs and thicket forming shrubs; base ratios on reference site data and key threats. |
| Planting approach | Phased planting (e.g., trees first, shrubs later) extends establishment time and increases costs. | Plant all species appropriate for site during the initial planting with appropriate spacing and ratios. |
| Planting density | Planting density is often drawn from forestry or climax community data. | Derive planting density from early- and mid-seral reference sites. |
| Plant mortality | Mortality among widely spaced plants creates large gaps; mortality of large planting stock can be costly. | Plant at reference densities to account for normal mortality; inter-plant to adjust composition and density. |
| Planting layout | Random layouts interfere with maintenance, while straight rows result in unnatural looking forests. | Plant in meandering rows to facilitate maintenance and create more natural looking forests. |
| Seed sourcing | Poor seed sourcing can introduce inappropriate species or genotypes. | Establish nursery contract(s) with designated seed collection areas. |
| Stock type selection | Nursery stock often have inappropriate root to shoot ratios. | Plant 1–2 year old bare-root seedlings grown to specifications. |
| Plant handling and installation | Planters lack familiarity with proper plant handling and installation techniques. | Establish detailed specifications for nurseries, cooler operators, and revegetation contractors. |
| Moisture conservation and irrigation | Moisture stress is a major cause of plant mortality; irrigation systems are costly, unreliable, water intensive, and they water weeds. | Employ early ring spray treatment to reduce competition from grasses. |
| Site use by wildlife | Wildlife can kill or damage a large percentage of planted trees and shrubs; protecting individual plants is costly and often ineffective. | Account for historic, current and anticipated wildlife use in species selection and layout; inter-plant with less palatable species. |
| Rodent damage control | Tubing and caging are costly, often produce plastic waste or float away and can be ineffective. | Employ ring spray treatment to prevent damage by voles and other rodents. |
| Vegetation monitoring | Monitoring methods often evaluate progress towards goals with no ecological basis. | Evaluate revegetation trajectories against ecologically based criteria derived from reference sites. |

and long term resilience of restored riparian plant communities. While some pressures can be mitigated through careful attention to site hydrology, soils, topography, and weed and herbivory risks, we have observed that the size, shape, and degree of continuity of a project can have a profound influence on project outcomes. With the increasing prominence of riparian shading programs for regulatory compliance, the exclusion of portions of riparian areas due to political boundaries, low shade credit value, landowner non-participation, or other reasons may have negative implications for the economic and social resiliency of revegetation programs. Moreover, narrow, convoluted, or discontinuous project boundaries represent missed opportunities that allow for the persistence of weed populations, reduce forest resilience, increase unit costs, and lower aesthetic values. R3 emphasizes the identification of project boundaries that eliminate unmanaged areas, increase connectivity, and minimize edge effects to the

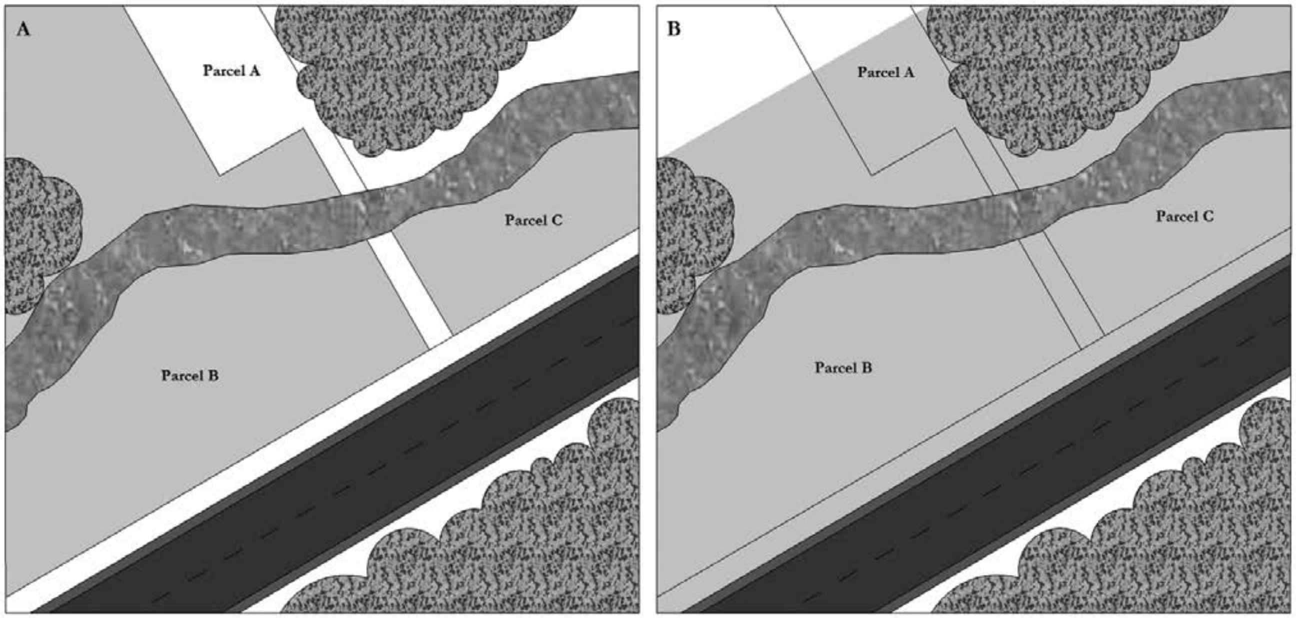


**Figure 1. Equal-sized riparian revegetation project area scenarios (in gray). One project (A) is defined by parcel boundaries and ease of access while the other (B) has 'defensible' boundaries designed to maximize continuity and reduce unmanaged area and edge effects.**

extent practicable by extending revegetation boundaries to the edge of the bankfull channel and to other natural or defensible boundaries on the floodplain terrace or adjacent uplands whenever possible (Figure 1). On many sites, we establish transitional shrub thickets along forest edges to reduce edge effects and re-invasion by shade intolerant weeds.

### *Site Preparation and Cover Establishment*

Existing conditions guide the development of R3 site preparation plans, and primary consideration is given to strategies that reduce weed competition during initial years of establishment. After experimenting with disking equipment as a means of preparing areas for planting, we found that access was often impractical and that it exacerbated weed conditions. We therefore consider soil disturbance undesirable except where soils have been severely compacted or altered. Depending on the extent

**Table 2. Sample reference site summary data from selected sites Western Oregon (Portland sites adapted from Query 2001, others from Guillozet, unpublished data).**

| General location | Forest type | Trees/ha | Shrubs/ha | Total stems/ha | Est. stand age |
|---|---|---|---|---|---|
| Portland | Ash floodplain | 544 | 30,117 | 30,660 | 70 |
| Buena Vista | Cottonwood/maple floodplain | 240 | 5,552 | 5,792 | 100 |
| Buena Vista | Ash/cottonwood floodplain | 425 | 6,506 | 6,931 | 50 |
| Portland | Cottonwood riparian | 235 | 3,398 | 3,632 | 80 |
| Buena Vista | Cottonwood riparian | 524 | 4,784 | 5,308 | 80 |
| Medford | Cottonwood riparian | 1,977 | 10,872 | 12,849 | 80 |
| Medford | Cottonwood riparian | 2,718 | 3,212 | 5,930 | 10 |
| Medford | Cottonwood riparian | 4,942 | 6,919 | 11,861 | 10 |
| Medford | Cottonwood riparian | 5,189 | 1,236 | 6,425 | 40 |
| Portland | Mixed conifer/hardwood rip. | 237 | 20,368 | 20,606 | 150 |
| Portland | Mixed conifer/hardwood rip. | 642 | 11,861 | 12,503 | 90 |
| Portland | Upland conifer | 7,771 | 4,757 | 12,528 | 10 |
| Portland | Upland conifer | 7,277 | 7,413 | 14,690 | 10 |
| Portland | Shrub-scrub wetland | 0 | 25,886 | 25,886 | 6 |
| Buena Vista | Shrub-scrub wetland | 284 | 7,791 | 8,075 | 30 |
| Portland | Forested wetland | 408 | 7,944 | 8,352 | 20 |

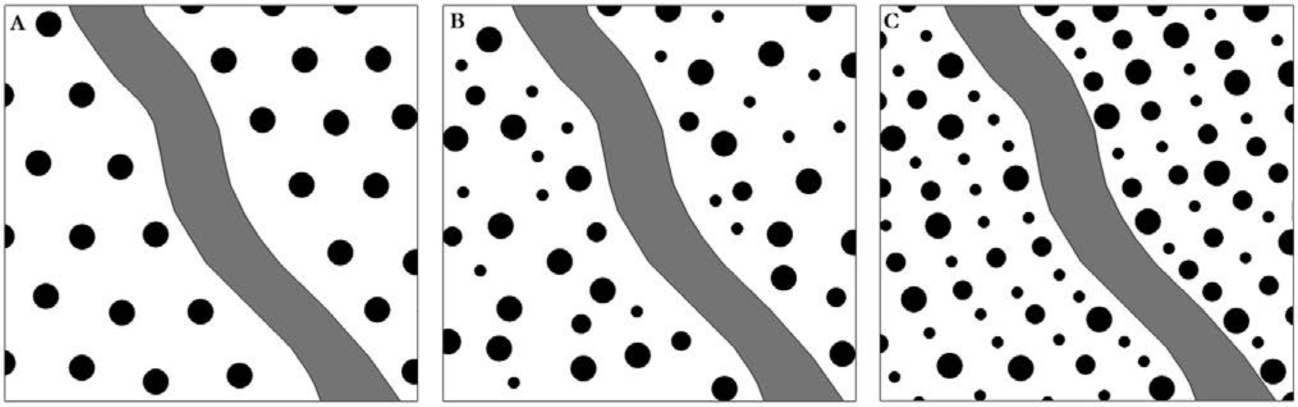


**Figure 2. Low density trees on grid (A), random layout with 1:1 tree-shrub ratio (B), typical R3 layout in curved rows with 1:3 tree-shrub ratio (C).**

and characteristics of existing weeds, effective site preparation typically includes mowing and brush clearing as well as spot or broadcast application of approved herbicides over a one- to two-year period. On sites with little or no native vegetation, flail mowing is the preferred method of brush removal, while experienced chainsaw crews provide an effective means of selective brush removal on both small and large sites. Following control and removal of undesired vegetation, we rely on seeding with a locally sourced two to three species mix of short-stature native grasses (e.g., *Agrostis exarata, Deschampsia elongata,* and *Deschampsia danthonioides*) to suppress weeds and reduce soil erosion while minimizing competition with planted seedlings. We spread seed at rates of 9 to 13 kilograms per hectare (roughly 8 to 12 pounds per acre) using belly crank or ATV spreaders on small sites and using no-till drilling on large sites. Equipment and operators for the latter are readily available in the Willamette Basin owing to its robust agricultural sector. Depending on the timing, site size, hydrology, soils, and weed conditions, seeding may be completed either before or after planting.

### *Planting Design*

Although trees may provide most of the eventual shading, high shrub densities function as a matrix for soil protection, wildlife forage and cover and ground-level shading for weed control. A key lesson during the development of R3 was recognition of the importance of structural and functional differences among arborescent shrubs, small shrubs, and thicket-forming shrubs. In developing planting plans we derive the species list, the target stem densities, and the ratios among trees and shrub types from the reference sites. We then account for existing vegetation and assess soils, hydrology, weed pressures, wildlife use, and other obvious limiting factors. On bare sites, total planted stems typically range from 5,400 to 6,400 stems per hectare (roughly 2,200 to 2,600 per acre). Trees typically represent fewer than 20 percent of total stems and thicket-forming shrubs often represent 60 to 70 percent of total shrubs. The R3 approach also relies heavily on inter-planting, which allows managers to offset initial mortality and adjust species composition and densities in response to observed ecological conditions. It is our standard practice to budget for the purchase and installation of 25 percent of the initial planting numbers in the second year of a project (e.g., initial planting at 6,000 stems/hectare × 25% = inter-planting at 1,500 stems/hectare).

The primary objectives of R3 planting plans are consistency with reference plant community composition, development of a multi-strata canopy, competitive exclusion of non-native species, and reduction of edge effects. Although native forbs play an important role in forest ecology, aggressive weeds can make their reintroduction impractical in the early stages of many revegetation projects. The R3 approach instead emphasizes native grass establishment followed by multi-strata canopy development to reduce weed cover and create future conditions more favorable to native forbs.

### *Planting Spacing and Layout*

Plant spacing in R3 is informed by reference site data and conditions in the planting area. Sites with severe weed problems or anticipated herbivory typically require more plants, while those with desirable herbaceous cover or with partial canopy cover are planted at lower densities. To eliminate the need for future thinning, our planting plans specify tree to shrub ratios that aim to establish appropriate spacing between large, slow growing and/or highly competition-sensitive trees such as Douglas fir (*Pseudotsuga menziesii*) and Oregon white oak (*Quercus garryana*). Planting layouts generally follow natural contours and take the form of meandering rows with regular row and plant spacing. Plant clustering by species or growth habit is achieved through repetition of rows or portions of rows (Figure 2). Depending on desired densities, row and plant spacing on bare ground typically range from 1 to 1.2 meters on center (approx. 3 to 4 feet). In addition to yielding more natural looking forests than straight rows

(Figure 2), this arrangement reduces costs by streamlining maintenance practices and increasing the visibility of small seedlings.

### Plant Sourcing and Stock Types

Unavailability of appropriate (species, genotypes, stock type, and size) nursery stock is a common limiting factor in revegetation projects. R3 practitioners have devised a system of multi-year contract growing arrangements with multiple nurseries in the Willamette Basin to reduce risk and build local capacity. Collaborative agreements across organizations to collectively source plant materials, provide greater security to growers, increase flexibility, and reduce plant costs. Contract growing also gives buyers greater leverage to limit seed collection to recognized seed zones or other pre-determined areas (e.g., Willamette Basin below 450 meters elevation). While this provides some assurance that plant materials are adapted to local conditions, revised seed collection standards that take into account the implications of climate change, elevation and ecological barriers for plant genetics are currently under development (see WWETAC 2013) and will be incorporated into future contracts.

The target seedling concept, described by Rose et al. (1990), identifies specific physiological and morphological seedling characteristics and serves as a valuable tool in stock type selection. Although most research comparing root development among containerized and bare-root stock has focused on conifer species used in timber production, there is no clear consensus on the advantage of either in terms of survivability, placing into question the higher plant purchase, transport, and installation costs associated with containerized stock (Hobbs 1984, Grossnickle 2005). While container-grown seedlings may demonstrate greater initial survival in a number of trials on droughty sites (Arnott 1975, Hobbs and Wearstler 1983, Burdett et al. 1984, Nilsson and Örlander 1995), other studies suggest that growth differences between stock types are temporary (Rose and Haase 2005).

Although factors such as project scale, accessibility, planned site preparation and maintenance practices, and current and potential stock type availability will often point to a preferred stock type, most stock types can yield acceptable results across a range of conditions. However, the larger the nursery stock the higher the purchase, transport and planting costs (Landis et al. 2010, Withrow-Robinson et al. 2011). R3 relies almost exclusively on 1–0, 1–1 or similar bare-root seedlings 30 to 60 centimeters tall, and on vegetative cuttings, as both are readily available in the Willamette Basin (2013 average contract cost: \$0.48 per seedling, \$0.15 per cutting) and can be planted more efficiently in large numbers. These attributes enable managers to adjust species composition in response to mortality at a relatively low cost. In comparison, average 3.8-liter (1 gallon) containerized plants sourced from the same nurseries costs an average of \$4.13 (2013 prices, for example see www.schollsvalley.com).

### Plant Handling and Installation

The bare-root planting season in the Willamette Basin typically extends from January through March, while containerized seedlings allow for fall, winter and spring planting. Although some planting stress is unavoidable under most planting conditions, severe stress is a major contributor to bare-root seedling mortality following outplanting (Grossnickle 2005). Planting stress can be minimized by planting seedlings properly and ensuring proper root-soil contact, which reduces seedling water stress and allows the seedling to initiate new root growth (Grossnickle 2005). It is critically important to protect bare-root seedlings at all times from freezing and drying during lifting, storage, transport and planting (Landis et al. 2010).

To prevent damage and loss, R3 nursery and plant storage contracts include detailed specifications for growing, packing and cooler storage. Once removed from the cooler, plants are kept covered at all times using reflective tarps and plant roots are wetted prior to planting. The sensitivity of bare-root stock underscores the R3 approach's reliance on qualified project managers and skilled planters who are familiar with planting in riparian areas. A skilled planter is familiar with the moisture, light, and soil requirements of different species and can plant 800–1,000 bare-root plants per day at an average cost of \$0.28 per plant. Project managers provide quality control over planting activities by inspecting periodically for proper placement, spacing, planting depth, root arrangement, and soil tamping.

### Site Maintenance

Frequent site visits throughout the growing season and effective manual, mechanical, and herbicide maintenance practices are among the most important factors in successful R3 projects. Such visits can reveal excessive competition from surrounding vegetation, moisture stress, and signs of herbivory early enough to allow for corrective measures. Following site preparation and planting, vegetation management typically includes either mowing, cutting, spot herbicide treatments, or a combination of these activities. On R3 projects, mowing has proved problematic, as the size of mowing equipment dictates row spacing that is often wider than desired. Moreover, mowing can lead to soil compaction and, because of potential impacts to ground nesting birds, is restricted by various agencies during the spring and early summer. In Oregon, these mowing restrictions coincide with the critical period for weed control. Although targeted cutting of problem areas by chainsaw crews has been used extensively and has proven effective, it is relatively expensive, and like mowing, can disrupt ground nesting birds. The combination of small-stature native grass cover and periodic spot herbicide has provided the most effective alternative to cutting or mowing. Specifically, a

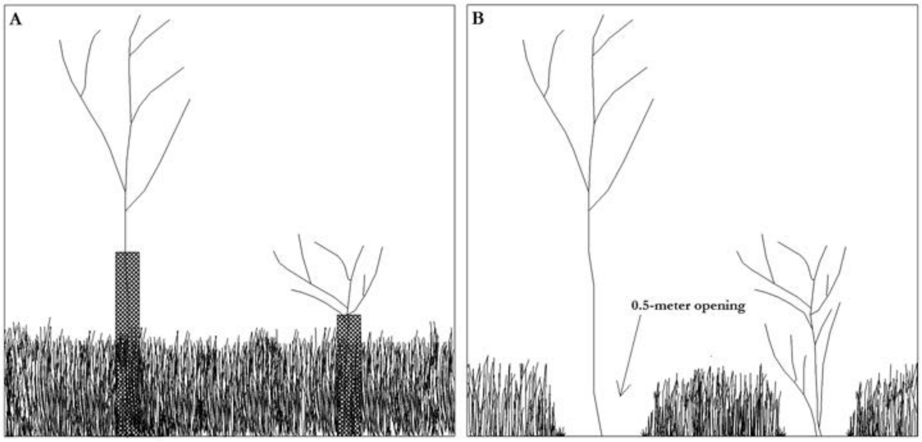


**Figure 3. Plastic tubing on trees and shrubs surrounded by tall grasses (A), which often results in moisture stress and rodent damage. Preferred R3 conditions (B) with short-stature native grass cover and early season grass control 'ring' spray, which conserves moisture and prevents plant girdling by rodents.**

moisture conserving ring spray around each plant in the spring or early summer reduces competition from grasses (Figure 3) and creates openings around plants that expose rodents to predators such as raptors, owls, and coyote. This practice has essentially eliminated girdling damage on R3 projects and, along with spot spraying, has provided adequate control of target weeds.

### *Irrigation*

In arid areas or during drought years, irrigation may reduce plant mortality. However, irrigation can be both impractical and costly on large or discontinuous projects. Irrigation systems are prone to breakdown, vandalism and damage during high flows, and plastic irrigation pipes are often left on sites permanently. In particularly arid areas or on dry soils mulching and hand-watering by crews with water tanks or pumps can provide a viable alternative to irrigation systems, but may be impractical due to high costs and water rights issues. In the Willamette Basin (mean June to September precipitation = 108 mm (NOAA 2013)), proper species selection and placement of appropriate nursery stock (e.g., small, bare-root stock with balanced root to shoot ratios) in combination with effective vegetation control around plants (e.g., ring sprays) have eliminated the need for irrigation on sites managed using the R3 approach since 2006. In the event of high plant mortality, inter-planting has been a more cost-effective strategy to offset losses.

### *Herbivory*

Wildlife habitat enhancement is often a goal of riparian revegetation, but wildlife may also impact our efforts. Ungulate browse can deform trees and shrubs, reduce growth and increase mortality, while voles and other rodents can damage or kill plants through bark girdling (Weigand et al. 1993, Withrow-Robinson et al. 2011). In the Willamette Basin, the historic removal of beaver and current re-colonization trends pose both management challenges and opportunities. While beaver promote ecological processes and functions, vegetation must be sufficiently established to support stable beaver populations.

By assessing historic and current use by wildlife via frequent field visits, and by planning for future use, R3 seeks to address the needs and impacts of wildlife through appropriate plant selection and placement, high planting densities and effective maintenance practices. For example, at sites with extensive browsing pressure or with existing or potential beaver activity, certain species are overplanted in high traffic or near-stream areas to provide adequate food sources and dam-building materials and to reduce pressure on other vegetation during establishment. Other options to reduce browse include the use of less palatable species or a greater emphasis on establishing thicket-forming shrubs. While plant protection tubes and cages can be effective if installed properly and maintained in uplands, they are prone to improper installation, degradation, and loss or damage during high water events (Stanturf et al. 2004). Plant protectors are often found girdling growing trees and are increasingly found as trash along Willamette Basin streams (W. Hudson, Oregon Watershed Enhancement Board, pers. comm.)

### *Vegetation Monitoring*

In evaluating revegetation treatments, an ecological perspective is often subordinate to the pressure to declare victory or conclude investigations while funds are available (Kondolf 1995, Prodgers et al. 2000). The use of percent survival to assess project success, as is common practice (see, for example, Smith 2012), may unintentionally incentivize project performance-based rather than ecologically-based management decisions because success is determined on the basis of the survival of an often arbitrary number of plants rather than on the achievement of ecological objectives such as shade establishment for water quality benefits or species and structural diversity for wildlife habitat and resilience against reinvasion by weeds. The R3 approach monitors vegetation trajectories independently of planting prescriptions through assessment of stem densities, tree to shrub ratios and non-native or invasive cover. Data from sample plots assigned at random within distinct plant communities are compared to project or programmatic

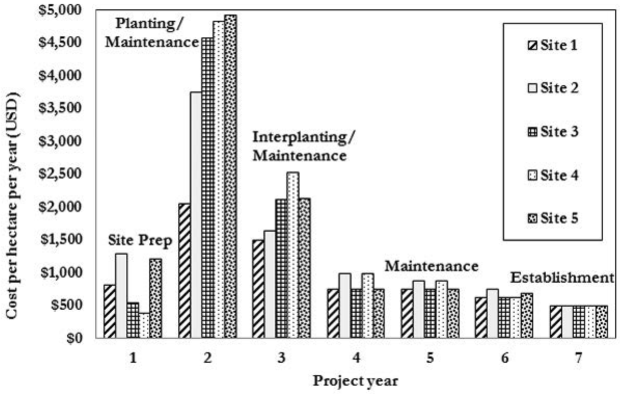


**Figure 4. Projected cost (USD per hectare) through forest establishment on example R3 project sites near Buena Vista, Oregon.**

revegetation targets informed by local reference sites. The size and number of plots varies and is based upon variability in the sample population (see Oregon Department of State Lands 2009).

## Sample Projects

The R3 approach as described in this paper reflects current practices as refined over a decade in an ongoing process. As such, projects that began in 2003 are different in substantive ways from those begun in 2013. Examples of improvements include an increase in mean stem density, greater attention to the establishment of native grass cover, the near elimination of mowing as a maintenance practice, increased use of shrubs as a percentage of total stems, and increased use of thicket-forming shrubs as a percentage of total shrubs. To provide examples of recent R3 implementation we selected five representative revegetation sites within a single project in Oregon's Willamette Basin. The sites are currently in varying stages of completion and, therefore, reflect a mix of both actual and projected costs. Together, they encompass 51.3 hectares (126.8 acres) of moderately to highly degraded former riparian or floodplain forest, and represent a range of site conditions and goals typical of R3 projects. The project is funded through multiple grants to a non-profit organization that hired the first author and a revegetation contractor to implement restoration plans. Prior to the start of work, Site 1 was a degraded riparian forest with substantial invasive weed cover, particularly Himalayan blackberry (*Rubus armeniacus*). Site 2 had been planted at roughly three meters (10 feet) on center circa 2002 with tubed trees and shrubs through the CREP program. The site was mowed for several years and subsequently invaded by blackberry, reed canary grass (*Phalaris arundinacea*) and a host of common agricultural weeds. Site 3 was a wetland dominated by reed canary grass for many decades. Site 4 had been a farmed field until 2011, and Site 5 was originally planted circa 2002 using a CREP approach and supported sparse native vegetation and extensive weed cover as of 2011.

Table 3 summarizes pre-implementation conditions, planting details, level of effort of different activities represented as a percentage of total cost, and the total cost per hectare. Total revegetation costs at these sites average $11,000 per hectare over a seven year period. Figure 4 presents data from the same sites and illustrates project implementation timelines and cost trends typical of R3 projects. Although implementation costs vary according to project location and size, site conditions, project manager, contractor, and other factors, in the first author's experience, R3 costs in the Willamette Basin typically range from $11,000 to $20,000 per hectare ($4,500 to $8,100 per acre).

## Conclusions

Riparian restoration project managers face a number of constraints in implementing revegetation projects. These include abbreviated field seasons, competing project needs, limited funding, short grant timelines, and poorly developed monitoring and evaluation criteria. Sharing and documenting information about effective practices can help practitioners and funders make informed decisions and increase the likelihood of success in the field. Peer-to-peer learning opportunities among project managers can foster a community-of-practice that can advance the science and practice of restoration.

This description of R3 is intended to encourage discussion and research on best practices for achieving desired future conditions as they relate to riparian revegetation, and we recognize that it may generate more questions than answers. Practitioners, regulators, and funders all play a role in advancing replicable approaches to restoring riparian corridors. Some priority areas for research and documentation from our perspective include:

1. Quantitative evaluation of existing R3 projects in comparison with other approaches used locally to evaluate outcomes and linkages between practices and ecological conditions (the second author will conduct an evaluation of Willamette Basin riparian revegetation projects in 2014).
2. Examination of reference site selection and data collection protocols to assess methodological rigor. In high-intensity restoration areas such as the Willamette Basin, historic botanical studies and contemporary data could be incorporated into a centralized database of reference sites to guide revegetation.
3. Application and possible modification of R3 approach for more arid environments and in areas lacking existing nursery and forestry contractor sectors.
4. Assessment of revegetation outcomes and costs in relation to the duration of site preparation, planting density and the intensity and duration of maintenance.

**Table 3. Summary of example R3 sites near Buena Vista, Oregon highlighting pre- and post-project conditions, planting details, and projected total cost per hectare.**

| | | | | | | | | Percent of total cost | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site no. | Initial site condition | Desired future condition | Area (ha) | Previous stems/ha (mean) | Planted stems/ha (mean) | No. of species planted | Planted tree to shrub ratio | Project mgt. | Site prep | Planting & inter-planting | Bare root plants | Native seed | Maintenance | Total cost/ ha |
| 1 | Degraded riparian forest | Mixed riparian/ gallery forest | 2.6 | 4,448 | 1,977 | 14 | 1 to 4 | 17.6% | 9.5% | 7.5% | 14.7% | 2.3% | 48.4% | $8,420 |
| 2 | Degraded CREP plantings (circa 2002) | Gallery forest | 28.8 | 2,224 | 3,459 | 23 | 1 to 3.5 | 13.2% | 11.4% | 9.4% | 18.5% | 1.3% | 46.2% | $11,222 |
| 3 | *Phalaris* dominated wetland | Shrub-scrub wetland | 2.3 | 0 | 5,930 | 7 | 1 to 5 | 13.1% | 4.8% | 12.0% | 31.6% | 1.8% | 36.7% | $11,284 |
| 4 | Farmed until 2011 | Gallery forest | 6.1 | 0 | 6,425 | 28 | 1 to 3.5 | 12.2% | 3.0% | 12.7% | 30.5% | 2.4% | 39.1% | $12,148 |
| 5 | Degraded plantings (circa 2002) | Mixed riparian/ gallery forest | 11.5 | 988 | 5,436 | 26 | 1 to 4 | 12.0% | 9.8% | 12.7% | 27.6% | 1.6% | 36.4% | $12,383 |
| | | **Average** | **10.3** | **1532** | **4645** | **19.6** | | **13.6%** | **7.7%** | **10.8%** | **24.6%** | **1.9%** | **41.4%** | **$11,091** |

5. Comparative evaluation of rates of reinvasion by shade tolerant and shade intolerant weed species in revegetated areas with single and multi-story canopies.
6. Long term post-establishment monitoring of vegetation dynamics with attention to tree, shrub, grass, forb, and weed populations with and without ongoing stewardship.

With hundreds of thousands of kilometers of riparian corridors in need of restoration and limited public funds for implementation, practitioners need to identify strategies that lower the unit cost and accelerate the pace of reestablishment of native riparian forests in sustainable ways. The R3 approach is grounded in ecological principles and geared towards producing outcomes consistent with restoration programming and the human desire to see "progress" for the investments made. As such, the approach represents an attempt to bridge the best available science with practice. This underscores the authors' interest in promoting dialog between academics and practitioners in order to encourage debate and structured inquiry about revegetation practices.

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