APPENDIX A. KEY RIPARIAN FUNCTIONS, SUPPORTING VEGETATIVE CONDITIONS, AND RIPARIAN BUFFER DESIGN CONSIDERATIONS

Riparian functions	**Vegetation conditions and** *functions supported*	**Riparian buffer design considerations**
Provide shade to keep water cool.	Shrubs and trees on the sunny side of the stream *Provide foliage to block sunlight.*	South and west sides of streams are most critical for shade plantings. Buffer width depends on stream size, slope, and orientation. This function can be attained relatively quickly.
Stabilize stream bank to prevent erosion.	Trees and shrubs on the stream bank and (on small streams) in the active channel *Roots hold soil, and stems slow water to reduce erosive force.*	A stream bend's inside bank requires a smaller buffer; its outside bank requires a larger buffer to account for channel migration. Vegetation within 25 feet of the channel provides most of the buffer's stabilization. This function gradually increases with development of surface cover and root structure.
Filter nutrients and sediments to maintain high-quality water.	Trees and shrubs at the upland edge of the riparian area *Vegetation cover slows and filters water flowing from adjacent uplands. Plant roots take up nutrients from the soil solution.*	Sediment filtration depends on slope, soil type, and other factors, such as the presence of drain tiles. A 50-foot buffer can provide substantial filtration of sediment from overland flow. Larger buffers may be needed to take up soluble nutrients and herbicides.
Modify stream flow; create resting cover pools or retain gravel to improve fish habitat.	Large trees falling into the stream *Woody debris lodged in the streambed slows and diverts water, causing gravel to accumulate. Water plunging over and circulating around woody debris forms and maintains pools.*	Most debris comes from trees directly adjacent to the stream channel. Landslides, floods, and debris flows can also provide significant debris, depending on landscape conditions beyond the riparian area.
Provide off-channel refuge.	Trees and shrubs along low areas of floodplain *Provides cover and slow-water areas for small fish overwintering in the lower Willamette system.*	Enhancement of existing sloughs and side channels may yield high-value benefits for fish habitat. This function can be quickly attained.
Provide nutrients to enrich aquatic system.	Vegetation overhanging the stream *Deposits leaves and twigs. Insects fall from vegetation into the water. Forms the basis of the aquatic food web in some streams.*	Most benefits come from vegetation hanging over or directly adjacent to the channel.
Provide habitat for nesting, roosting, foraging, and other terrestrial wildlife activity.	Dense areas of shrubs with an overstory including large live trees and dead trees (snags) *Shrubs and trees provide nesting and hiding cover and may provide corridors for wildlife passage.*	Buffer width depends on habitats and species of concern. Large buffers needed for wildlife corridors. Even with fast-growing species, development of these functions may be very slow.

APPENDIX B. PROMOTING NATURAL REGENERATION

Promoting natural regeneration (i.e., growth from seeds, roots, and stems) of trees and shrubs already on the site can help establish desired vegetation with less expense and effort than planting seedlings. This may be the core of a passive restoration strategy or a way to add diversity to a planting.

Other advantages of natural regeneration are that species are genetically adapted to local conditions and, especially with vegetative reproduction, set for rapid growth. Greater reliance on natural regeneration can also increase the cover of desirable riparian plants. However, natural regeneration alone generally is not a reliable way to meet establishment goals for species composition or an adequate number of trees and shrubs.

Conditions must be right for natural regeneration to occur:

- Temporary freedom from vegetative competition
- Available sources of seed (of desired species)
- Abundant soil moisture

Conditions for natural regeneration are often most favorable close to the stream, where there is abundant soil moisture and where seasonal flooding prevents invasive species such as blackberry from establishing. Natural regeneration also frequently occurs in a pulse after a disturbance, such as a major flood that has cleared streamside vegetation and exposed or deposited fresh sand and gravel.

These conditions are ideal for germinating seeds of black cottonwood, willow, alder, and many other riparian species. They are not favorable for many conifers. Oregon ash, Oregon white oak, and hawthorn (both the native Douglas and invasive English) are likely to spread into wet meadow areas, even with some weed competition. Many riparian species also regenerate vegetatively, including resprouting from the root crown, root suckering, layering, and sprouting from stem fragments. This makes natural regeneration a useful but often unreliable source of recovery in years when seed production is low or matches poorly with natural disturbances, or when you want to develop woody cover farther from the active stream channel.

What can be done to enhance natural regeneration?

- Kill or cut back competing vegetation. Riparian plantings often contain more desired woody plants than first meet the eye. Locate and flag these plants before cutting.
- Stimulate root suckering, layering, and sprouting by cutting back competing vegetation twice per year. Black cottonwood (*Populus trichocarpa*) and sandbar willow (*Salix exigua*) sprout vigorously from underground shoot buds on lateral roots. A temporary reprieve from competition can help these species move rapidly into previously unoccupied areas (figure 22).
- Minimize cover of competing vegetation to stimulate germination and rapid early growth of seedlings of desirable species. A large amount of seed falls into riparian areas, but new plants can regenerate only under favorable conditions. It isn't important to eliminate competitors entirely, but you must reduce their cover to low levels while desirable species get established.
- Protect plants from livestock or other animal damage with fencing or individual tree protection.

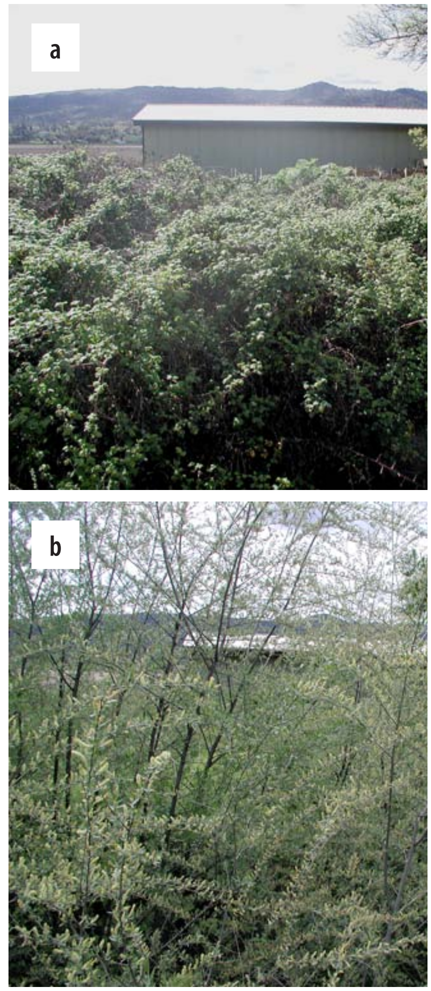

Figure 22. Two seasons after Himalayan blackberry was cut back on this site (a), sandbar willow has made a good recovery (b).

Photos by Max Bennett, © Oregon State University.

APPENDIX C. PROJECT DESIGN FEATURES AND CONSIDERATIONS

You considered functional goals (e.g., shade, bank stabilization, and habitat) when planning the project and selecting species. Optimize those functions with a thoughtful layout. Consult others; staff from soil and water conservation districts, watershed councils, and the Natural Resources Conservation Service generally have extensive experience with these practical design issues.

Buffer width

There is no one-size-fits-all buffer width. Wider buffers generally provide more benefits, but beyond a certain size, there may be relatively little increase in benefit for a relatively large increase in buffer width.

Optimal buffer widths vary depending on the desired riparian functions. For bank stability, relatively narrow buffers suffice. For wildlife habitat or travel corridors, wider buffers may be required (see Appendix A, page 22).

Consider a variable-width buffer. Good places for wider buffers are the outside bank of a stream bend (so the entire buffer isn't lost when the channel migrates) and on low terraces and low-gradient reaches (to enhance bank stability and off-channel habitat were flooding is more frequent).

On forestlands, the Oregon Forest Practice Act dictates minimum buffer widths. On agricultural lands, there are no specific buffer-width requirements; owners must comply with local water-quality management plans established under Oregon Senate Bill 1010. Contact your local soil and water conservation district or watershed council to learn about local water-quality management plans. City or county jurisdictions may have ordinances dictating buffer width.

Location

Some functions are more location-dependent than others. Vegetation on the south and west sides of the stream provides direct shade, which helps moderate water temperatures more than similar vegetation on the north side. Habitat functions (e.g., food and nesting) are not strongly related to position. Bank stability may be a key functional goal in areas subject to scour or stream meanders.

Access requirements

Provide access and adequate space between trees for any machinery to be used. Consider the benefits of rows for maintenance (e.g., mowing and spraying). Regular rows and adequate spacing between rows (5 to 10 feet) are needed for most small tractors and ATVs. Rows can look natural; they do not need to be straight lines. Sweeping curves work, too. Closer spacing and irregular tree distribution are OK if you will use smaller mowers, backpack sprayers, or hand tools.

Fencing and other livestock and wildlife controls

Standard woven wire and electric fencing are adequate for domestic livestock but require maintenance (figure 23). Carefully managed rotational livestock grazing can be compatible with riparian planting without fencing out the entire riparian area. However, cross-fencing to establish multiple pastures is key.

Deer and elk can jump easily over livestock fencing, so 8-foot or higher fencing is needed to protect plants from these animals. This can be prohibitively expensive; individual tree protectors often are used instead. An 18-inch-high chicken wire fence placed between the stream and planted stock keeps out most beaver and nutria.

File photo, © Oregon State University.

Figure 23. Riparian buffer installed next to a farm field. A stream is at left, outside the photo frame. In this case, livestock fencing (at right in photo) is essential to the success of the buffer planting.

Spacing and arrangement

The future diversity of your riparian woodland will depend not just on the species you select but also on the spacing and arrangement of your planting. Your design should reflect both short- and long-term goals.

Plant spacing

Appropriate plant spacing depends on several (sometimes competing) factors:

- Tree size, stand structure, and species composition needed to meet a project's functional goals
- Species characteristics (size, growth rate, form, and shade tolerance)
- Need for rapid establishment and occupancy by seedlings (increasing their ability to compete with weeds)
- How long and how well you can control competing weeds
- How quickly and to what degree seedlings compete with each other (affecting tree size, stand structure, and species composition)
- Your ability to thin in a timely manner

Mixed-species plantings

Mixed-species riparian plantings generally serve two purposes:

1. They provide "insurance" to cover uncertainties associated with seedling survival and species adaptation.
2. They establish a diverse plant community that will provide key habitat functions in the future.

The most common approach to developing a mixed-species planting is to use a random mix of species. This serves the first purpose but not necessarily the second.

Differing early growth rates affect how species interact and compete. Trees that establish and grow quickly often do so at the expense of neighboring plants, occupying space and consuming resources needed by each. Slower-growing trees fall behind and, depending on degree of crowding and their shade tolerance, may eventually die unless the planting is thinned. In a single-species stand, this competition affects the size and number of trees surviving but not the species present. In a mixed-species planting, competition favors one species over another and tends to shift the planting toward the faster-growing species. Diversity of the planting decreases as slower-growing species die, and any functional goals associated with these species won't be realized.

Research with a wide range of plants has demonstrated that this interaction is more pronounced the more dissimilar the growth rates among competing species. The interaction also is sensitive to plant spacing (density). The closer the spacing, the faster and more complete the displacement of the slower-growing species (figure 24a).

Strategies to allow slower-growing species (of a given shade tolerance) to survive longer include wider spacing (figure 24b) and clusters of individual species (figure 24c). Plants at the edge of a cluster of slow-growing species will be lost, but those inside are a safe distance from faster-growing competitors and can survive. Clustering is a good strategy to use when you want to plant close enough to cover planting losses and encourage rapid site capture but may be unsure of your future capacity for management (both weed control and thinning).

Consult with Oregon State University Forestry and Natural Resources Extension for more information about competition, stand development, and spacing and arrangement strategies for creating diverse riparian forests.

Research and demonstration of mixed-species plantings

Growing mixtures of species is challenging and requires good information about growth rates and other plant characteristics. Unfortunately, such information isn't available for many restoration species growing in riparian conditions. Ecological principals and established forestry practices can provide useful guidance, but demonstration and applied research are desperately needed.

A network of simple plots across a range of Willamette Valley soils would provide valuable information for current and future restoration project managers. Contact the authors if your watershed council or soil and water conservation district would be interested in contributing to this effort.

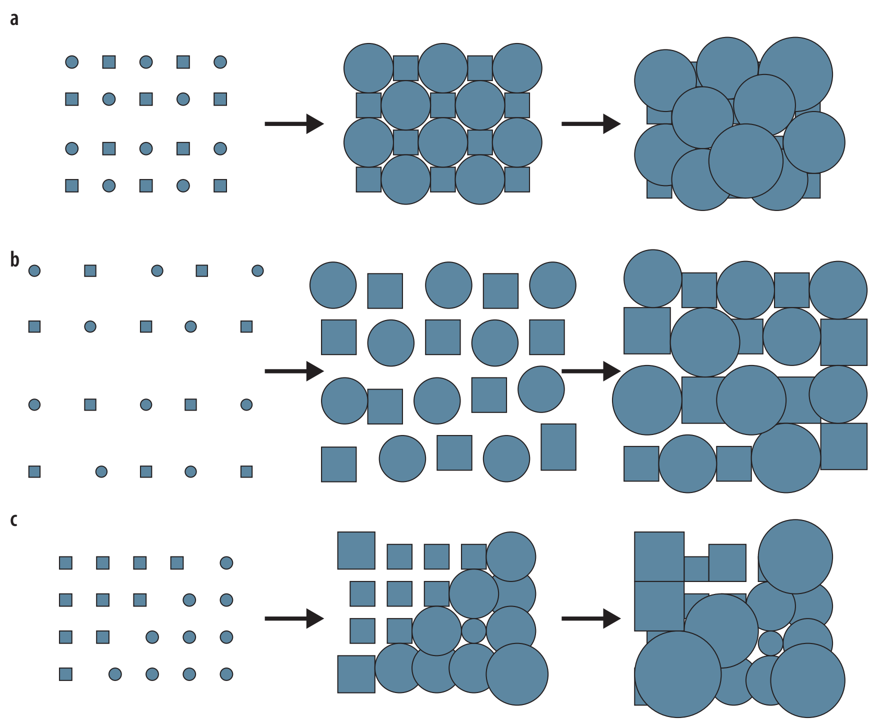

Figure 24. Mixed-species plantings have many advantages, but how the species are mixed at planting can lead to different outcomes as the trees and shrubs grow: (a) two species with different growth rates intermixed at a close spacing, (b) two species intermixed at wider spacing, and (c) two species clustered.

APPENDIX D. SAMPLE MONITORING QUESTIONS, OBJECTIVES, AND TECHNIQUES

Monitoring question	Objective	Technique
How many trees, stream frontage, or area planted? Where?	Document the project for project managers, funders, etc.	Include this information in your project documentation and monitoring plan.
Are the planted trees threatened by weeds or animal damage?	Assess immediate threats to tree vigor and survival and need for action.	Visual inspection of planting area. Timing: The spring after planting is most critical. Inspect at least once per season.
Did the planted trees survive?	Determine overall success of the planting. Is replanting necessary (if below some threshold)?	Visual inspection or intensive measurement. Walk the site to get a general sense of tree survival, or tally every tree or a representative sample of trees to determine survival rate. Flagged tree locations can be helpful. Timing: Inspect at the end of the growing season. The first growing season is an important benchmark; most mortality occurs in the first year.
Are the planted trees vigorous?	Evaluate success of the planting. Vigor is one criterion.	Visual inspection or intensive measurement. Indicators of vigor include plant size, leaf size, bud size, needle length, leaf length, and foliage color. Timing: Inspect during the growing season.
How fast are trees growing?	Determine overall success of the planting. Also, determine how growth varies by planting site, species, treatment, and other variables.	Visual inspection or intensive measurement. Height is less sensitive than diameter to effects of vegetative competition. Thus, differences in diameter often are used to evaluate treatment effects, such as different site preparation methods.
Are trees "free to grow"?	"Free to grow" is an important benchmark for project success. At this stage, trees should be able to dominate the site without further intervention.	Free-to-grow trees are vigorous, not threatened by competing vegetation, and poised for further growth and site dominance without additional intervention. Determining whether a tree is free to grow is somewhat subjective. Timing: Reaching free-to-grow stage is site specific. Upland conifers plantings usually require 4 to 6 years.
Are trees doing better in one area than another? Areas may differ ecologically (e.g., soils and drainage) or in treatments (e.g., site preparation).	Determine success of each section of the planting. Also, learn about factors affecting plants on the site and what might be done differently next time.	Visual inspection or intensive measurement. Compare tree survival, vigor, and growth (e.g., height, diameter, and stem volume).
What are the major reasons trees died?	Learn about factors affecting plants on the site and what might be done differently next time.	Visual inspection or intensive measurement. Note any evidence of trees dying from overtopping/encroachment of competing vegetation, lack of water, lack of nutrients, animal damage, etc.
Is the riparian condition trend positive (e.g., is cover of desirable vegetation increasing)?	Determine whether riparian goals are being met.	Photo monitoring or intensive measurement.
Did the project increase shade to the stream?	Determine whether riparian goals are being met.	Photo monitoring may show increases in stream cover. Intensive measurement (e.g., with a solar pathfinder or fish-eye lens) is needed to quantify increases in shade.
Did the project reduce nitrate input to streams from adjacent farmlands?	Determine whether riparian goals are being met.	Intensive measurement.