Potential Responses of Riparian Vegetation to Dam Removal

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Throughout the world, riparian habitats have been dramatically modified from their natural condition. Dams are one of the principal causes of these changes, because of their alteration of water and sediment regimes (Nilsson and Berggren 2000). Because of the array of ecological goods and services provided by natural riparian ecosystems (Naiman and Decamps 1997), their conservation and restoration have become the focus of many land and water managers. Efforts to restore riparian habitats and other riverine ecosystems have included the management of flow releases downstream of dams to more closely mimic natural flows (Poff et al. 1997), but dam removal has received little attention as a possible approach to riparian restoration.

The riparian vegetation that grows in post–dam removal environments interacts strongly with other factors that are generally given more direct consideration in dam removal efforts. For example, riparian vegetation can stabilize sediments in former reservoir pools, perhaps reducing downstream sediment transport that can harm aquatic ecosystems (Bednarek 2001). Vegetation that occupies new surfaces downstream and within the former reservoir pool will influence use by wildlife and for human recreation (AR/FE/TU 1999).

Vegetation response to dam removal is highly dependent on changes to the physical environment. Vegetation at the interface between a water body and the surrounding uplands is dominantly structured by the hydrologic gradient. Sites along this gradient differ in the duration, frequency, and timing of inundation (generally referred to as *hydroperiod).* Species differences in hydroperiod tolerances and requirements produce zonation and pattern in species composition and general cover types along the hydrologic gradient (figure 1). Dam removal may change aspects of the hydrological regime that structure riparian vegetation, including flood and low-flow regimes and associated water table dynamics. Further, dam removal will generally result in the creation of two classes of bare sediment that can be colonized by riparian plants: (1) downstream deposits transported from the former reservoir pool and upstream sources and (2) surfaces within the former reservoir pool (figure 1).

> DAM REMOVAL GENERALLY CAUSES CHANGES TO ASPECTS OF THE PHYSICAL ENVIRONMENT THAT INFLUENCE THE ESTABLISHMENT AND GROWTH OF RIPARIAN VEGETATION

The distribution and character of new bare substrates will vary tremendously across sites. Removal of small dams in systems with low sediment transport may result in few downstream changes and relatively simple upstream changes associated with vegetation colonization and succession on the former lake bottom. Removal of dams that have trapped large quantities of sediment could result in erosion of those deposits and transport of sediment downstream. The physical (e.g., particle-size distribution) and chemical (e.g., macronutrient and micronutrient status) character of sediments may be different from conditions that existed before dam removal, potentially affecting species composition of

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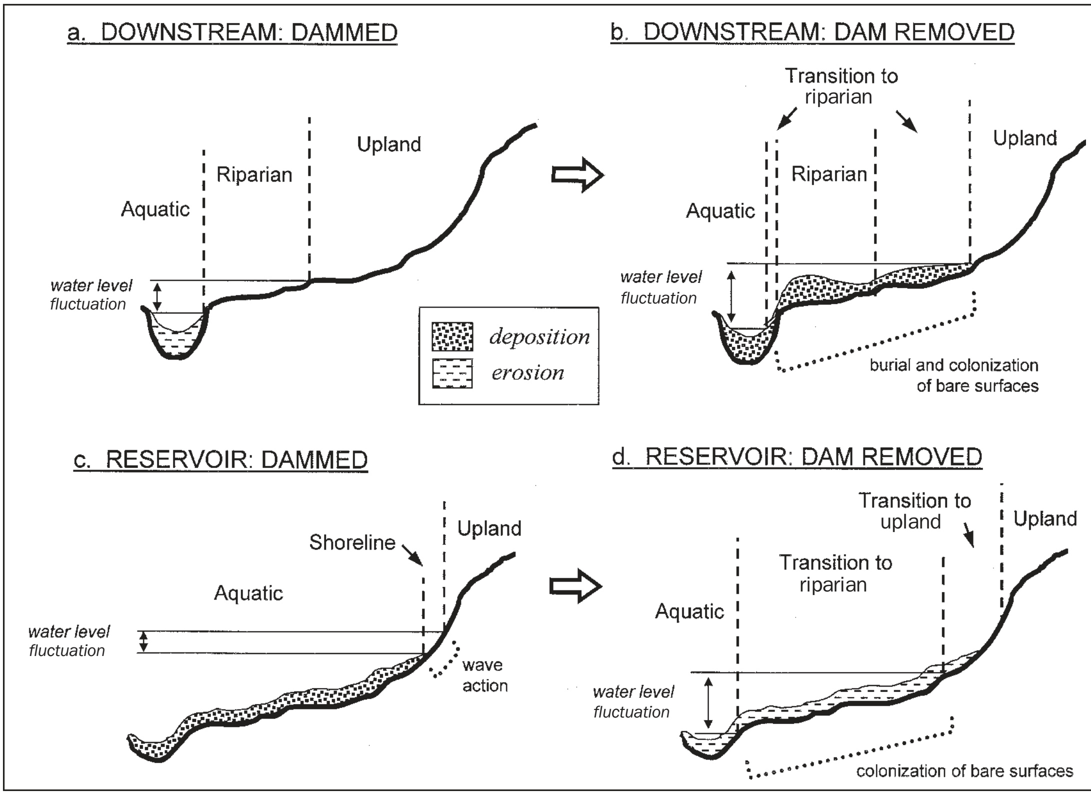

Figure 1. General changes to key physical environmental factors and vegetation following dam removal. (a) During the dammed period, the downstream river may experience some channel degradation, a decrease in flow variability (depicted as water-level fluctuation), and a narrowed riparian zone. (b) Following dam removal, transport of upstream river sediment and sediment trapped in the reservoir may lead to a pulse of sediment deposition, which, combined with increased flooding, may both stress existing vegetation and create sites for the colonization and establishment of new vegetation. (c) During the dammed period, vegetation along the reservoir shoreline is often confined to a narrow band, and its composition is driven largely by fluctuations in the reservoir water level and wave action. (d) Following dam removal, large areas of former reservoir bottom are exposed and may be colonized by riparian or upland plants. Trapped sediments behind the dam may be subject to erosion.

plants colonizing substrates within the former reservoir pool or downstream deposits. For example, invasions of exotic plants are sometimes associated with increased nitrogen availability (Dukes and Mooney 1999), and soils containing high micronutrient or heavy metal levels may support only plants tolerant of these ions (Marschner 1995).

The character of the new flow regime may also influence vegetation development following dam removal. Where dam removal results in a return to a natural flow regime, benefits to native plants and communities may accrue over time (Poff et al. 1997, Stromberg 2001). On rivers with multiple dams, a dam removal may result in only spatially limited or partial restoration of natural flows. Along rivers in which reservoir capacity has been severely reduced by sedimentation, flow regimes may no longer be substantially different from natural flows, and dam removal will have little effect on the downstream flows.

Riparian plant communities are often part of primary successions, with colonizing plants becoming established on bare, moist, alluvial sediments like those expected to be present following dam removal. Life history characteristics of plants can have an important effect on the trajectory of a riparian primary succession (Walker et al. 1986). Initial colonization of bare sediment in riparian environments is accomplished primarily through a combination of wind and water dispersal, although animal dispersal may bring a more diverse set of propagules to a site over time (Kalliola et al. 1991, Galatowitsch et al. 1999). Dam removal should increase the efficiency of long-distance transport of seeds by water (Jansson et al. 2000), which may enhance riparian restoration efforts. The timing of viable seed dispersal (Walker et al. 1986), substrate characteristics (Krasny et al. 1988), and soil moisture influence which species are able to successfully colonize a site. Soil seed banks contribute to vegetation dynamics along lake or reservoir shorelines and along margins of confined rivers (Keddy and Reznicek 1986) and, following dam removal, would be expected to play an important role in primary succession on newly exposed sediments upstream of the dam. Seeds of some emergent wetland species buried by sediment and submerged in water have been estimated to remain viable for between 45 and 400 years (Leck 1989). Vegetative reproduction can also be an important strategy for expansion of remnant or founder populations (Krasny et al. 1988, Kalliola et al. 1991).

In this article, we review the scant information documenting responses of terrestrial vegetation to dam removal and derive expected responses both upstream and downstream of the former dam on the basis of empirical and theoretical relationships between riparian plants, stream hydrology, and fluvial processes. We evaluate case studies from North America of planned or completed dam removals, natural analogs of dam removal, and alternative strategies of releasing and exposing water and sediment. We consider transient and equilibrium responses and the effects of different dam removal strategies on native and exotic plants. We focus on the natural establishment of vegetation following dam removal, although we also discuss active measures such as planting.

Figure 2. (a) Pioneer riparian vegetation colonizing a new sediment deposit. Fresh alluvial deposits such as these would be expected to occur on river reaches downstream of a dam removal. (b) Tree mortality associated with burial by sediment transported and deposited following a dam failure in Rocky Mountain National Park, Colorado. Photographs by Patrick Shafroth.

Downstream responses

Effects of a downstream sediment pulse. Dams generally trap and store sediment, often depleting reaches downstream (Williams and Wolman 1984). Dam removal may result in the downstream transport of stored sediment, which is usually seen as a potential problem (Simons and Simons 1991, Hotchkiss et al. 2001). For example, the sediment may kill fish, clog spawning gravels, or damage neighboring property. However, this transient pulse of sediment provides an opportunity for channel change and the creation of new surfaces suitable for the reproduction of riparian pioneer species (figures 1, 2a). Such surfaces may have been scarce following dam construction; thus, from the perspective of riparian vegetation, sediment released upon dam removal may be a benefit (Semmens and Osterkamp 2001).

Most dam removals to date have involved small reservoirs with small amounts of sediment, and few data are available concerning the effects of the downstream pulses of sediment on channel morphology and vegetation (Hotchkiss et al. 2001). There are, however, better-described cases of sediment pulses resulting from other causes, including hydraulic mining (Gilbert 1917, James 1989), timber cutting (Madej and Ozaki 1996), volcanic eruption (Major et al. 2000), large floods (Jarrett and Costa 1993), and dam maintenance (Wohl and Cenderelli 2000). Several generalizations may be drawn from this literature. As the sediment pulse travels downstream, its amplitude decreases and its wavelength increases over time (Gilbert 1917, Simons and Simons 1991, Pizzuto 2002). At a point along the stream, the pulse may be observed as a transient increase in bed elevation or in the rate of sediment transport. Because fine particles are transported more easily than coarse particles, the sediment pulse may be sorted over time, with finer particles moving downstream more rapidly. The trailing limb of this pulse can take the form of exponential decay, and it may take decades for sediment loads to return to prepulse conditions (James 1989, Simons and Simons 1991). The sediment pulse may partially or completely fill channels, resulting in temporary or permanent channel avulsion. Avulsion and fluctuations in bed elevation often leave behind terrace deposits (James 1989) that may persist for centuries or more. Vegetation may colonize these terrace deposits, as with some valley oak *(Quercus lobata)* forests in California's Central Valley. Other surfaces associated with temporally and spatially variable aggradation and degradation of the sediment pulse will be colonized by vegetation, as has been described for mudflows associated with volcanic eruption (Halpern and Harmon 1983).

In addition to creating new alluvial surfaces, sediment deposition downstream of a removed dam could bury existing vegetation (figure 2b). Riparian species vary in their tolerance of high sedimentation rates (Hupp 1988). If vegetation downstream of dams has succeeded to late seral stages (Johnson 1992), then dominant species in these communities are likely to be less tolerant than pioneering species of burial by sediment. In 1982, a dam breach in Rocky Mountain National Park resulted in a large flood that deposited a 0.18 square-kilometer (km^2) alluvial fan that was up to 13.4 meters (m) thick (average thickness = 1.6 m; Jarrett and Costa 1993). Some vegetation died immediately because of complete burial (Keigley 1993), while many trees succumbed over a period of years, probably because of the effects of anoxic soils and accumulations of toxic levels of micronutrients (figure 2b; Barrick and Noble 1993).

Effects of a naturalized downstream flow regime.

Along rivers, the hydrologic regime interacts strongly with the geomorphic setting to influence the establishment and growth of riparian plants. Dam removal could restore natural hydrologic regimes, which can contribute to the rehabilitation of native plant communities (Poff et al. 1997, Taylor et al. 1999, Stromberg 2001). Regulated flow regimes are generally less variable than unregulated flows, and some vegetation downstream of dams is more competitive under relatively homogenous flow regimes. The timing, magnitude, and duration of flood, flood recession, and baseflows strongly influence riparian vegetation (Rood et al. 1998, Friedman and Auble 2000, Nilsson and Berggren 2000). For example, cottonwood *(Populus* spp.), willow *(Salix* spp.), and many other riparian species native to North America are pioneers that colonize bare sites produced by flood disturbance. By reducing flood magnitude and frequency, dams decrease establishment opportunities for such species (Johnson 1992) and can improve the competitive ability of shade-tolerant exotic species that do not depend upon disturbance, such as Russian-olive *(Elaeagnus angustifolia;* Katz 2001). However, even if dam removal reduces available habitat for seedlings of exotic species, established adults may persist for decades until a flood, drought, age-related factors, or some other agent kills them. Persistence of large woody plants established under the former regulated flow regime could indefinitely impede the resumption of channel movement after dam removal because of their stabilizing influence on channel banks.

Case study: Elwha River, Washington. Large quantities of sediment are predicted to be transported downstream following the proposed removal of the Elwha Dam and Glines Canyon Dam on the Elwha River, Washington (Hoffman and Winter 1996). Results of current sediment modeling efforts (USDOI 1996) predict that 15% to 35% of the coarse sediment (sand, gravel, and cobbles) and about half of the fine sediment (silt- and clay-size particles) would be eroded from the two reservoirs following dam removal. The remaining sediment would be left along the reservoir margins as a series of terraces. Fine-sediment concentrations released from the reservoirs would be high during periods of dam removal, typically 200 to 1000 parts per million (ppm) but occasionally as high as 30,000 to 50,000 ppm. After the dams are removed, fine sediment concentrations would be low during periods of low flow and high during flood flows that erode channels in the reservoir areas. Within 2 to 5 years, concentrations would return to natural levels. Coarse sediment would aggrade in the relatively steep reaches of the river up to 15 centimeters (cm). Sediment aggradation in moderate-gradient alluvial reaches would promote natural patterns of lateral channel migration, especially near the river's mouth. Over the short term (up to 5 years), this could potentially increase river stages during the 100-year flood up to 1 m. Over the long term (50 years), aggradation could continue and increase existing river stages during the 100-year flood up to 1.5 m with an average increase of 0.75 m. Coarse sediment would enlarge the delta at the river's mouth to a size and character similar to that of predam conditions. As sediment modeling of this basin advances over the years, estimates of the magnitude and timing of sediment transport will become more refined. Yet current results provide an effective framework for predicting vegetation responses to dam removal.

Currently, red alder *(Alnus rubra)* is much more prevalent than black cottonwood *(Populus trichocarpa)* and native willows *(Salix* spp.) along the Elwha River downstream of the dams (figure 3). On the basis of predicted changes in fluvial geomorphology following dam removal, it appears that *Populus* and *Salix* would be favored in the colonization of alluvial reaches of the Elwha River. The life history, ecology, and physiology of these genera are well adapted to the natural flow regimes and sediment–deposition patterns predicted for the Elwha River (Braatne et al. 1996). The relatively high volumes of sediment transport and deposition in alluvial reaches subsequent to dam removal will not favor red alder. Several studies have shown that red alder is vulnerable to hypoxic conditions arising from sediment deposition or extended periods of inundation (Harrington et al. 1994). Therefore, a decrease in red alder and an increase in black cottonwood and willow would be expected in alluvial reaches following dam removal. Additional evidence for these changes in riparian vegetation can be found in the extensive cottonwood forests of the Dungeness River, an adjacent, undammed basin on the Olympic Peninsula of Washington (Dunlap 1991).

Figure 3. Young red alder trees (**Alnus rubra**) *line the channel and midchannel bars of the Elwha River, Washington, while older black cottonwoods* (**Populus trichocarpa**) *occupy older, higher surfaces. Conditions resulting from proposed dam removals on the Elwha River could lead to a decrease in red alder and an increase in black cottonwood. Photograph by Patrick Shafroth.*

Upstream responses

Vegetation within the former reservoir pool. Upstream of the dam, dam removal exposes areas of bare ground that were formerly under water, and river discharge (rather than reservoir storage) controls water stages. This will generally produce shifts from the always inundated aquatic zone to mostly inundated and occasionally inundated wetland and riparian vegetation zones, and from inundated or groundwater-affected zones to upland vegetation (figure 1). Thus dam removal may lead to mortality of vegetation along the former reservoir margin, especially if it is sensitive to water table declines associated with the drawdown. The distribution and location of changes in hydroperiods will depend on the topography and stage–discharge relations that develop following dam removal. In many cases, accumulation of sediment behind the reservoir will have altered the topography. If the new stream channel downcuts to near its previous elevation faster than the overall area erodes, then the distribution of hydroperiods in the reservoir pool may be drier following dam removal than before the dam was constructed (Lenhart 2000). On the other hand, partial dam removals in which a lowered control structure is left in place will yield a new storage capacity and effective stage–volume relation and could produce a new set of hydroperiods that may be wetter than those of the predam river.

Initially, vegetation is unlikely to be in equilibrium with the new distribution of hydroperiods. Rather, there will be a transition phase involving colonization of extensive bare areas or mud flats uncovered as water stages decline with the draining of the reservoir (figure 4). Dense, natural revegetation of these areas during the growing season has been observed within weeks in humid regions (AR/FE/TU 1999), while vegetation cover can take years to recover in less productive settings, such as subalpine reservoir margins in the Rocky Mountains (Mansfield 1993). Propagules of early colonizing plants may be present in seed banks or may be dispersed from adjacent areas. The initial colonizing plants can have a substantial long-term influence on plant composition through the persistence of long-lived individuals, vegetative reproduction, relatively higher seed production of those species, and alterations of the physical environment (Mansfield 1993). Initial plant colonists of sites characteristic of former reservoir bottoms (bare, moist, nutrient-rich, with a depauperate seed bank) tend to be weedy plants with typical ruderal traits such as rapid growth, high levels of seed production, and effective dispersal mechanisms. This group of plants may include a relatively high fraction of invasive, nonnative species (Galatowitsch et al. 1999, Lenhart 2000).

Case study: Removal of small dams in Wisconsin. Many small dams in the northeast and upper Midwest were built between the mid-1800s and early 1900s to power lumber and flour mills. Because of abundant water resources and the early development of dams for mechanical and small-scale hydroelectric energy, the state of Wisconsin has more than 3600 dams. Safety and economic reasons (i.e., where repair costs greatly exceeded removal costs) have led to the removal of more than 70 dams since 1950 in Wisconsin (Born et al. 1998, AR/FE/TU 1999).

Lenhart (2000) performed a retrospective analysis of natural vegetation recolonization in five former impoundments in Wisconsin. Two sites represented long-term (more than 40 years) recovery periods, whereas three sites had recovered in 3 to 5 years. Across all sites, high-nutrient sediments, ranging in depth from 25 to 200 cm, had been deposited over predam soils. Vegetation at the three younger sites had low species diversity and were dominated by large, monotypic stands of pioneer species like stinging nettle *(Urtica dioica)*, reed canary grass *(Phalaris arundinacea)*, and rice-cut grass *(Leersia oryzoides)*. The plant communities observed on the

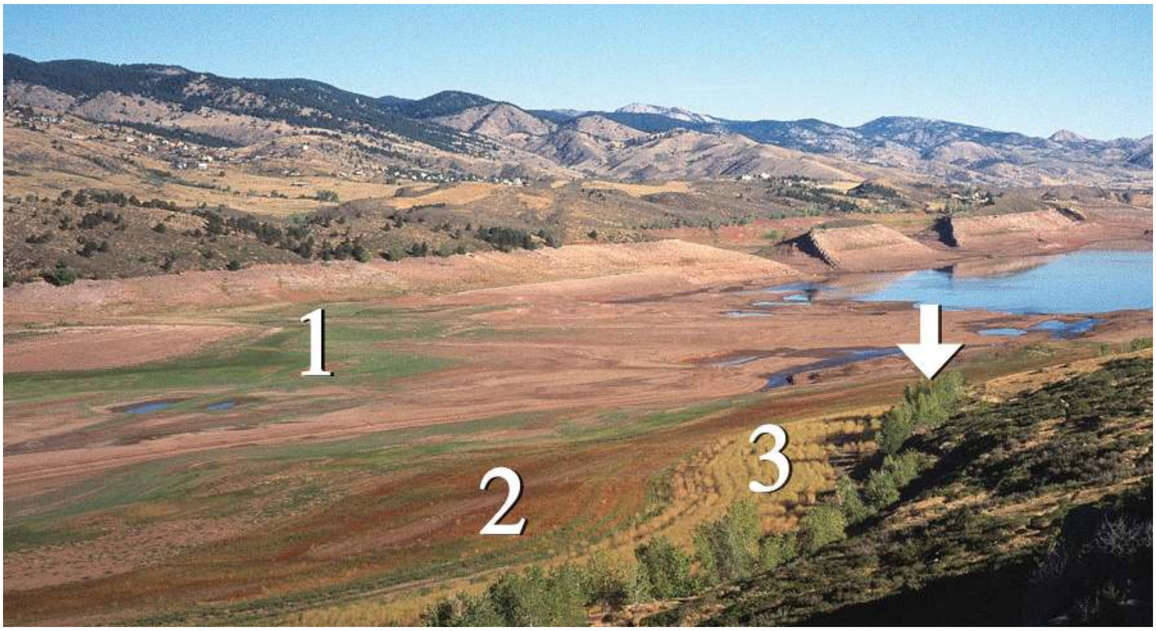

Figure 4. Vegetation colonization on the exposed bottom of Horsetooth Reservoir, Colorado. Between January 2000 and October 2001, water was drawn down 32 meters to enable dam repairs, reducing the water surface area from 621 to 77 hectares. Numbers refer to bands of vegetation dominated by the following nonnative species: (1) goosefoot (**Chenopodium glaucum**)*, (2) smartweed* (**Polygonum lapathifolium** *and* **P. persicaria**)*, (3) sweet clover* (**Melilotus** *spp.). The arrow points to mature cottonwood trees* (**Populus deltoides**) *that approximate the high water line. Photograph by Patrick Shafroth.*

younger sites did not resemble any native communities. Young sites tended to be composed of a high fraction of wetland plants, which colonized the moist surfaces that were exposed following dam removal. Over time, sites became drier and were dominated by more xeric species. The two older sites had higher species diversity but included a higher percentage of nonnative species.

Management considerations

Restoration potential. Dam removal should not always be expected to restore riparian ecosystems to their predam condition (figure 5). A spectrum of outcomes is possible, given the variability in predam conditions, the responses of the system to the dam, and the responses to dam removal (Zedler 1999). Ecological systems frequently exhibit hysteresis and time-lagged responses, the details of which are not clear with respect to riparian vegetation, although a transient phase of 50 to 100 years has been observed when systems respond to dam construction and operation (Petts 1987, Johnson 1998). Legacies of flow regulation such as altered channel morphology, species composition, and age structure may result in a delayed response of the system to naturalized flows. Even if dam removal restored the natural flow regime, effects of dam removal would vary regionally with factors such as climate, flood regime, geology, and fluvial processes associated with riparian vegetation establishment (Friedman and Auble 2000). Other anthropogenic impacts to a river system, such as adjacent groundwater pumping, channel stabilization, and agricultural and residential development, could prevent a return to predam conditions (figure 5). Effects of extreme events that occurred before but not during the dammed period (Katz 2001) or climate differences in the predam and postdam removal periods could also influence the response. Despite these possible limitations, dam removal has the potential to restore valuable components of riparian ecosystems, and some management actions could enhance this potential.

Managing for a beneficial transient sediment pulse. In some dam removal situations, relatively small pulses of sediment could promote enough channel change to create surfaces suitable for the establishment of riparian forest, without greatly damaging other resources. It could be argued that there is little value in managing for a transient benefit, because eventually trees established as a result of the sediment pulse would die. However, this view underestimates the importance of transient events in structuring populations of disturbance-dependent, long-lived species. For example, the cottonwood gallery forests along the Platte River system are a product of an adjustment in channel size following water management (Johnson 1998). Establishment of these forests was a transient event, not an equilibrium expression of the predam or postdam flow or sediment regime. Once established, such forests exist for more than a century, which is longer than the life of many dams. Given the persistent effects of transient events in these ecosystems, managing the sediment pulse following dam removal could be an efficient conservation strategy.

Controlling the reservoir drawdown. The timing and pattern of drawdown heavily influences the species composition of bare, moist areas by exposing sites at times that do or do not match the life history characteristics of various species with respect to germination and early seedling establishment requirements. Much practical experience with manipulating drawdowns to achieve desired mixes of herbaceous species is embodied in the wildlife–management strategy of "moist soil management" (Fredricksen and Taylor 1982). Many refuges and waterfowl management areas actively manipulate drawdowns in shallow constructed impoundments or moist soil units to grow specific species with desired food and cover value for wildlife. Similar approaches have been effectively employed in riparian restoration efforts to encourage natural establishment of desired native trees and shrubs (Roelle and Gladwin 1999). In arid and semiarid landscapes, where seedling establishment requirements for native riparian trees are often much wetter than the conditions they require as adults, the plants established during the transition or drawdown phase may persist and dominate the drier postdam regime for many decades. Recruitment of cypress *(Taxodium distichum)* and tupelo *(Nyssa aquatica),* after extended drawdown of a large impoundment in the southeastern United States suggests that natural establishment of bottomland hardwood forest could be expected following dam removal, assuming there are upstream sources of seed, that large numbers of seeds were produced the previous season, and that subsequent water levels do not exceed average seedling height for extended periods (Keeland and Conner 1999). Few dam removal projects have attempted to manipulate the timing and pattern of drawdown during the transition phase so as to produce desired vegetation. Where the reservoir pool can be lowered by draining and pumping before any work is done on the dam structure, there is tremendous potential for effective, even multiyear control over the plant community by managing water stages during the transition phase (ASCE 1997).

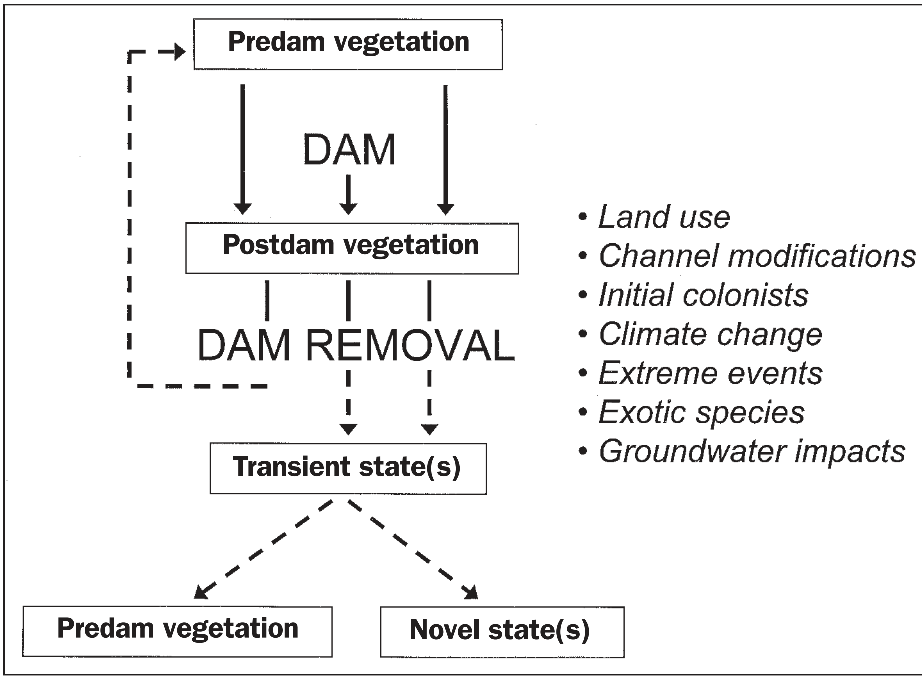

Figure 5. Multiple pathways of riparian vegetation change from unregulated conditions through postdam removal states. Riparian vegetation may respond to dam construction and operation in various ways, and multiple trajectories are possible following dam removal, depending on initial conditions and the nature of hydrologic and geomorphic change. Other factors, including those listed next to the flow diagram, also influence riparian vegetation response. As a result, in many cases, riparian vegetation is unlikely to quickly return to its predam condition.

Invasive species. Although dam removals represent a significant opportunity for riparian habitat restoration, they also provide opportunities for invasion of undesirable, nonnative species (figure 4; Galatowitsch et al. 1999, Lenhart 2000). High levels of physical disturbance result in significant proportions of exotic species in many riparian floras (Planty-Tabacchi et al. 1996, Tickner et al. 2001). The extensive, bare, nutrient-rich sediments of the former impoundment provide a substrate that may favor weedy, nonnative plants (Dukes and Mooney 1999). Once established, nonnative weeds may inhibit the establishment of native species, thus reducing plant and animal species diversity (Galatowitsch et al. 1999, Middleton 1999) and influencing succession (Hobbs and Mooney 1993). Where the risk of nonnative vegetation establishment is high, a more managed approach to vegetation establishment following dam removal may be warranted.

Active revegetation. Dam removal plans may include broadcast seeding or limited tree planting aimed at precluding the establishment of undesirable nonnative species or stabilizing sediments in the former reservoir pool (ASCE 1997, AR/FE/TU 1999). Additional reasons for active revegetation following dam removal include creating habitat diversity and improving recreational use. Secondary measures such as installation of structures to slow or reduce bank erosion, construction of fenced exclosures to manage livestock, and multiyear irrigation of plantings have been necessary elements of revegetation efforts in arid and semiarid regions of the United States (Briggs 1996). Active revegetation of riparian shrubs and trees in the western United States has often failed because of insufficient understanding of establishment and survival requirements of native species and continued livestock grazing following planting (Kauffman et al. 1995, Briggs 1996).

Plantings of early successional native species with relatively high growth rates may be an effective means of minimizing the establishment of exotic plant species and initiating natural successional processes. Dense stands of native woody plants, such as cottonwood and willow, may effectively shade out and thus exclude many exotic herbaceous annual and perennial plants. In contrast, planting slow growing, late-successional or climax species following dam removal may provide exotic weeds with an initial advantage. In the midwestern United States, plants such as smartweeds *(Polygonum* spp.), rice-cut grass, barnyard grass *(Echinochloa crus-galli),* and sod-forming sedges *(Carex* spp.) often naturally recolonize disturbed prairie wetlands. Other species, which may effectively compete with aggressive weeds, have been suggested for planting as potential native cover crops. These include late-season grasses such as *Spartina pectinata* and forbs such as *Coreopsis* spp. and *Ratibida* spp. (Galatowitsch and van der Valk 1994). Cover crops may quickly occupy sites, stabilizing the soil surface and usurping space that might otherwise be taken by less desirable species. In subsequent years, more slowly growing species may gradually replace the annuals. In the southwestern United States, attempts to actively restore native riparian understory species by planting, removal of nonnatives, and use of commercial soil amendments were ineffective, largely because of the rapid regrowth or establishment of nonnative species already on site (Wolden and Stromberg 1997). Recommendations for future efforts suggested that (a) seeding should be done over several years to accommodate climatic and hydrologic variability, (b) seed mixes should include species reflecting a diversity of life-history traits so species can sort out across the range of fine-scale environmental conditions that may exist at the restoration site, and (c) some weedy native annuals may compete well initially with nonnatives.

The assumption that a diverse set of species will naturally disperse to and become established on a site following the planting of a few of the dominant species is not always valid—such planting has produced stands of relatively low diversity in reforested bottomland hardwood forests (Allen 1997). Experimentation can make seed selection more efficient by helping to determine which species will recruit well naturally versus which need to be planted and which and how many species are necessary to develop desired ecosystem functions (Zedler et al. 2001).

Ultimately, a fundamental goal of any attempt to actively reestablish self-sustaining wetland and riparian vegetation should be to restore or reestablish key physical processes such as natural flow variability and channel change (Middleton 1999, Stromberg 2001). Such physical processes integrate terrestrial and aquatic elements of the watershed, producing spatially and temporally distinctive patterns of vegetation establishment (Scott et al. 1996). Restoration of key physical processes, in concert with active revegetation, enhances long-term success. The displacement of native wetland and riparian vegetation by invasive, nonnative species is typically associated with alteration of the natural hydrologic regime and land use practices that reduce flooding, lower water tables, and alter soil properties (Briggs 1996). Efforts aimed at actively revegetating herbaceous (Wolden and Stromberg 1997, Middleton 1999) and woody (Briggs 1996) vegetation have benefited from natural flooding.

Research needs

There is a strong need for more quantitative studies of the response of vegetation to dam removal. This should include rigorous monitoring of new or recent dam removals or retrospective analyses of older sites. Long-term studies will be necessary to elucidate potentially complex pathways of vegetation change. The potential for the generation of novel plant communities associated with the unusual physical conditions that may follow dam removal represents an intriguing topic of ecological research. Manipulative experiments could be used to test different management techniques, including controlled drawdowns and various planting approaches. Given the well-documented importance of fluvial geomorphic and hydrologic conditions in structuring riparian vegetation, botanists and plant ecologists should seek collaborations with physical scientists and couple plant response models to models used to estimate water and sediment dynamics following dam removal.

Acknowledgments

Thanks to David Hart and LeRoy Poff for organizing the dam removal symposium at the 2001 annual meeting of the Ecological Society of America and to The Pew Charitable Trusts for providing support that helped us to complete this article. Thanks also to those who shared their experiences with dam removal, including Madeline Fisher, Jeff Connor, and Chris Lenhart. The comments of David Hart and three anonymous reviewers improved the manuscript. This manuscript was prepared by employees of the US Department of the Interior, US Geological Survey, and therefore may not be copyrighted.

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