

LITERATURE SURVEY RESTORATION OF AQUATIC HABITATS NORTHWEST TERRITORIES

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BAKER CREEK AT THE GIANT MINE, YELLOWKNIFE, NWT LACKS EFFECTIVE RIPARIAN VEGETATION.

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1.0 INTRODUCTION

Effective restoration is an integral part of any remediation project. Restoration treatments are often not considered until after the remedial work is complete and the site is “cleaned up”. If a riparian area is within a remediation project restoration becomes even more essential since riparian areas provide important ecological functions, goods and services.

This report presents the results of a literature search that was conducted for Fisheries and Oceans Canada, Northwest Territories on restoration of aquatic habitats. Details of the methods employed in the search as well as the results are provided below.

2.0 METHODS

Databases accessible through Google, Google Scholar and Mendelay search engines were employed to locate relevant references for this document. In addition materials available at Polster Environmental Services Ltd. were studied. Additional references were located from Poster Environmental Services library, citations in selected papers and from recommendations from other researchers. A focus on methods and information about Canada and the United States was applied to limit the tremendous amount of data available. However, some articles of very pertinent topics from other countries were included. Key search words were “riparian restoration”, “wetland restoration “and "soil bioengineering". Using search words such as “boreal” and “northern” limited the search greatly and was soon abandoned. Abstracts were downloaded and reviewed and then the most relevant papers were listed.

3.0 RESULTS

A total of 137 articles are listed including a wide range of topics. Some topics were very specific, i.e. the interactions of salmon and bear in riparian forests in Alaska (Helfield and Naiman 2006) to general articles about the importance of riparian restoration (Laub et al. 2009). The materials specific to northern Canada were very limited. The majority of materials were from American sources. Of critical interest were several articles on the importance of wetlands to help mitigate climate change (Nilsson et al. 2013). It is hoped that this literature review will be helpful in improving riparian restoration in the Northwest Territories.

Anderson, J. T., Osbourne, J. D., & Ward, R. L. (2004). Integrating riparian restoration to promote wildlife habitat with natural stream channel design on mine land habitats. *Proceedings of the National Meeting of the American Society of Mining and Reclamation*, 21, 47–73. Retrieved from http://www.asmr.us/Publications/Conference_Proceedings/2004/0047-Anderson WV.pdf

The role of natural streams and associated riparian habitat in structuring vertebrate communities is an important wildlife management issue in human-impacted environments. Many studies have illustrated the value of healthy riparian ecosystems in providing basic habitat requirements for a broad array of vertebrate taxa. In regions where coal mining is widespread and vital to state and local economies, it is important to address the effects of different mining practices on riparian ecosystems. Two major negative impacts of mining on natural streams and stream corridors is the alteration of physical characteristics of the stream itself and fragmentation of riparian habitat. Natural stream channel design has become a popular means of mitigating for impacts to stream channel structure; however, less emphasis has been placed on the science of creating riparian corridors to connect riparian areas fragmented by human impacts such as mining. This paper provides a background and review of literature regarding the importance of riparian ecosystems to vertebrates, the effects of mining on vertebrate populations in riparian habitats, and the use of natural stream design in riparian restoration. We provide suggestions and recommendations on how to manage riparian corridors on mine lands and outline a research agenda on wildlife in relationship to riparian corridors on mine land sites.

Audet, J., Elsgaard, L., Kjaergaard, C., Larsen, S. E., & Hoffmann, C. C. (2013). Greenhouse gas emissions from a Danish riparian wetland before and after restoration. *Ecological Engineering*, 57, 170–182.

Restoration of riparian wetlands often aims at increasing the removal of nitrogen and phosphorus by re-establishing the hydrological connectivity between the stream and the surrounding floodplain. However, the geochemically reduced soil conditions in the newly restored area may favor the emission of greenhouse gases (GHG) such as nitrous oxide (N₂O) and methane (CH₄). To evaluate this risk the fluxes of N₂O, CH₄ and carbon dioxide from ecosystem respiration (Reco) were determined prior to and after restoration of a stream and its adjacent riparian areas. The data collected during the first year after restoration revealed spatially and seasonally variable N₂O emissions ranging from 0.1 to 3.1 gNm⁻²y⁻¹, but no statistically significant effect of the restoration on N₂O emission was observed as tested for comparable 8-month periods before and after restoration. The re-establishment of a high groundwater level (GWL) induced a significant increase in CH₄ emissions ($p < 0.001$), from -0.04 to 31.7 gCm⁻² at a permanently flooded, restored area during comparable 8-month periods before and after restoration. Ecosystem respiration at the restored sites decreased or remained stable after the restoration, but a decrease in Reco was also observed at a control site. According to mixed model statistical analyses both the soil temperature at 10cm depth (T(-10cm)) and GWL were apparent controllers of CH₄ and Reco. Nitrous oxide emissions were related to N content in the top soil. Annual CH₄ emissions the first year after restoration were comparable to those of natural riparian wetland sites and the increased CH₄ emission appeared to be compensated for by a decrease in Reco, while the effect of the restoration on N₂O was more uncertain-not least because of large spatial variation.

Bernhardt, E.S. and M. A. Palmer. (2011). Evaluating River Restoration¹. *Ecological Applications* 21:1925–1925. <http://dx.doi.org/10.1890/11-0644.1>

Bernhardt, E. S., and Palmer, M.A. (2011). River restoration: the fuzzy logic of repairing reaches to reverse catchment scale degradation. *Ecological Applications*. 21, 1926-1931.

River restoration is an increasingly common approach utilized to reverse past degradation of freshwater ecosystems and to mitigate the anticipated damage to freshwaters from future development and resource-extraction activities. While the practice of river restoration has grown exponentially over the last several decades, there has been little empirical evaluation of whether restoration projects individually or cumulatively achieve the legally mandated goals of improving the structure and function of streams and rivers. New efforts to evaluate river restoration projects that use channel reconfiguration as a methodology for improving stream ecosystem structure and function are finding little evidence for measurable ecological improvement. While designed channels may have less-incised banks and greater sinuosity than the degraded streams they replace, these reach-scale efforts do not appear to be effectively mitigating the physical, hydrological, or chemical alterations that are responsible for the loss of sensitive taxa and the declines in water quality that typically motivate restoration efforts. Here we briefly summarize this new literature, including the collection of papers within this Invited Feature, and provide our perspective on the limitations of current restoration.

Bernhardt, E. S., Sudduth, E. B., Palmer, M. A., Allan, J. D., Meyer, J. L., Alexander, G., Pagano, L. (2007). Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners. *Restoration Ecology*, 15, 482–493.

Despite expenditures of more than 1 billion dollars annually, there is little information available about project motivations, actions, and results for the vast majority of river restoration efforts. We performed confidential telephone interviews with 317 restoration project managers from across the United States with the goals of (1) assessing project motivations and the metrics of project evaluation and (2) estimating the proportion of projects that set and meet criteria for ecologically successful river restoration projects. According to project managers, ecological degradation typically motivated restoration projects, but post-project appearance and positive public opinion were the most commonly used metrics of success. Less than half of all projects set measurable objectives for their projects, but nearly two-thirds of all interviewees felt that their projects had been “completely successful.” Projects that we classified as highly effective were distinct from the full database in that most had significant community involvement and an advisory committee. Interviews revealed that many restoration practitioners are frustrated by the lack of funding for and emphasis on project monitoring. To remedy this, we recommend a national program of strategic monitoring focused on a subset of future projects. Our interviews also suggest that merely conducting and publishing more scientific studies will not lead to significant improvements in restoration practice; direct, collaborative involvement between scientists, managers, and practitioners is required for forward progress in the science and application of river restoration.

Beschta, R. L., & Ripple, W. J. (2010). Recovering Riparian Plant Communities with Wolves in Northern Yellowstone, USA. *Restoration Ecology*, 18, 380–389.

Gray wolves (*Canis lupus*) were extirpated from Yellowstone National Park in the 1920s. The ensuing seven decades marked a period when wild ungulates, principally Elk (*Cervus elaphus*), extensively used woody browse species in the upper Gallatin and northern winter ranges, thus limiting the capability of establishing plants to grow more than 100 cm in height. Following the reintroduction of wolves in the mid-1990s, we evaluated patterns of woody browse species recovery within riparian areas of these winter ranges. Measurements indicated that cottonwood (*Populus* spp.) recruitment (growth of seedlings/sprouts into tall saplings and trees) was occurring for the first time in several decades. A spatially patchy increase in the heights of young willow (*Salix* sp.) and cottonwood in the upper Gallatin and northern winter ranges, respectively, was also found within riparian transects comprising nearly 20 km in total length. Within some transects, heights of woody species have begun to exceed 200 cm (the approximate upper browse level of Elk). Results are consistent with the reestablishment of a tri-level trophic cascade involving wolves, ungulates, and riparian vegetation. We additionally present conceptual models of vegetation recovery, illustrating differences in plant height responses to behaviorally and density-mediated trophic cascades. Northern Yellowstone's "experiment in time," whereby wolves were removed and then reintroduced, provides new insights regarding how top predators can influence the structure and biodiversity of terrestrial ecosystems. Restoration ecologists and policymakers should consider the potential benefits of large predators as an option for helping restore degraded ecosystems.

Bolton, S. M., & Shellberg, J. (2001). Ecological Issues in Floodplains and Riparian Corridors. *Final White Papers*, 88 <http://hdl.handle.net/1773/17030>.

As part of the process outlined in Washington's Statewide Strategy to Recover Salmon: Extinction is Not an Option. The Washington Departments of Fish and Wildlife, Ecology, and Transportation were charged to develop Aquatic Habitat Guidelines employing an integrated approach to marine, freshwater, and riparian habitat protection and restoration. Guidelines will be issued, as funding allows, in a series of manuals addressing many aspects of aquatic and riparian habitat protection and restoration. This document is one of a series of white papers developed to provide a scientific and technical basis for developing Aquatic Habitat Guidelines. The white papers address the current understanding of impacts of development and land management activities on aquatic habitat, and potential mitigation for these impacts. The following topics are addressed in the white paper series: 1) Over-water structures - marine 2) Over-water structures - freshwater 3) Over-water structures - treated wood issues 4) Water crossings 5) Channel design 6) Marine and estuarine shoreline modification issues 7) Ecological issues in floodplain and riparian corridors 8) Dredging - marine 9) Dredging and gravel removal – freshwater Individual white papers will not necessarily result in a corresponding guidance document. Instead, guidance documents, addressing management and technical assistance, may incorporate information from one or more of the white papers. Opportunities to participate in guidelines development through scoping, workshops, and reviewing draft guidance materials will be available to all interested parties. Principal investigators were selected for specific white paper topics based on their acknowledged expertise. The scope of work for their projects requested a "comprehensive

but not exhaustive" review of the peer-reviewed literature, symposia literature, and technical (gray) literature, with an emphasis on the peer-reviewed literature. Readers of this report can therefore expect a broad review of the literature, which is current through late 2000. The coverage will vary among papers depending on research conducted on the subject and reported in the scientific and technical literature. Analysis of project specific monitoring, mitigation studies and similar efforts are beyond the scope of this program. Each white paper includes some or all of these elements: overview of the Aquatic Habitat Guidelines program, overview of the subject white paper, assessment of the state of the knowledge, summary of existing guidance, recommendations for future guidelines, glossary of technical terms, and bibliography. The overarching goal of the Aquatic Habitat Guidelines program is to protect and promote fully functioning fish and wildlife habitat through comprehensive and effective management of activities affecting Washington's aquatic and riparian ecosystems. These aquatic and riparian habitats include, but are not limited to rearing, spawning, refuge, feeding, and migration habitat elements for fish and wildlife.

Borders, B. D., Pushnik, J. C., & Wood, D. M. (2006). Comparison of leaf litter decomposition rates in restored and mature riparian forests on the Sacramento River, California. *Restoration Ecology*, 14, p. 308–315.

One of the largest riparian restoration projects in the United States is currently taking place in California on the Sacramento River. Nearly 2,000 ha of land adjacent to the river channel have been revegetated with native riparian species in an effort to re-establish riparian forests. The objective of this study was to compare leaf litter decomposition rates in restored riparian forests to those in mature, naturally established riparian forests, in order to monitor the development of this ecosystem function in restored forests. Leaf litter decomposition rates were measured over 1 year in six restored riparian forests (4, 7, and 9 years old) and two mature remnant riparian forests (> 50 years old), in order to test two hypotheses: (1) decomposition rates of restored and mature forests are significantly different and (2) decomposition rates in the chronosequence of restored forests are moving along a trajectory, approaching the decomposition rates characteristic of mature forests as they age. Statistical analyses revealed no significant differences in annual decay rates among the four different forest ages and no trajectory among leaf litter decomposition rates in restored forests. These results suggest that a functionally equivalent process of leaf litter decomposition occurs in both restored and naturally established forests and show promise for the efficiency of nutrient cycling processes in these restored forests.

Brookshire, E.N.J., Kauffman, J. B., Lytjen, D. and Otting, N. (2002). Cumulative Effects of Wild Ungulate and Livestock Herbivory on Riparian Willows. *Oecologia*, Vol. 132, No. 4 (Aug., 2002), pp. 559-566. <http://www.jstor.org/stable/4223376>

We examined the effects of wild ungulates (deer and elk) and domestic sheep browsing on the growth, structure, and reproductive effort of two common willow species, *Salix boothii* and *S. geyeriana*, in a montane northeast Oregon riparian zone. With the use of exclosures, large herbivore effects on willows were studied in an area browsed by native mammals only and an adjacent area in which domestic sheep also lightly grazed during summer months. Growth variables were repeatedly measured on individual plants over a 5-year period to understand physiognomic and flowering responses of native willows to different levels of

browsing pressure. At the beginning of the study, all willows were intensely browsed but were significantly taller in the area browsed only by native mammals than in the area also grazed by sheep (69 versus 51 cm, respectively). Willows inside exclosures responded with pronounced increases in height, crown area, and basal stem diameters while the stature of browsed plants outside exclosures stayed constant or declined. In the area browsed by both sheep and wild herbivores, the size of browsed plants remained at pre-treatment levels (<60 cm in height) for the duration of the study. There was no significant difference in growth rates of enclosed willows, indicating that current herbivory was the primary cause of growth retardation in the study area. Foliar area was strongly correlated with basal stem numbers for enclosed plants but much less so for browsed plants. Willows inside exclosures had more than twice as much foliar area per stem. Stem diameters were a positive function of crown area: stem-number ratios, suggesting lower photosynthetic potential was correlated with diminished radial growth among browsed plants. No flowering was observed until 2 years after exclusion when plants inside all exclosures and browsed willows in the wild ungulate area responded with a large pulse in flowering. Browsed plants in the sheep + wild ungulate area did not flower. The number of catkins produced per plant was significantly associated with willow height and plants <70 cm in height did not flower, thus suggesting a size threshold for reproduction in these species. Our results suggest that even relatively light levels of domestic livestock grazing, when coupled with intense wild ungulate browsing, can strongly affect plant structure and limit reproduction of riparian willows.

Buijs, A. E. (2009). Public support for river restoration. A mixed-method study into local residents' support for and framing of river management and ecological restoration in the Dutch floodplains. *Journal of Environmental Management*, 90, 2680–2689.

Residents use three distinct frames to give meaning to river restoration projects: (i) an attachment frame, focusing on cultural heritage and place attachment (ii) an attractive nature frame, focusing on nature as attractive living space and the intrinsic value of nature (iii) a rurality frame, focusing on rural values, agriculture and cultural heritage. Resistance to river restoration plans stems from the attachment and rurality frames. People using these frames challenge safety arguments for river restoration and highlight potential threats to sense of place and to agriculture. In the areas surveyed, the project initiator's focus on biodiversity and safety did not resonate very well among the local community, because of their diverging views on nature. Practical implications of the study include the need to incorporate public perception into river restoration projects and the potential for project initiators to form strategic alliances with local residents to promote ecological restoration in combination with river restoration.

Buijse, A. D., Coops, H., Staras, M., Jans, L. H., van Geest, G. J., Grifts, R. E., Roozen, F. C. J. M. (2002). Restoration strategies for river floodplains along large lowland rivers in Europe. *Freshwater Biology*, 47, 889–907.

Most temperate rivers are heavily regulated and characterised by incised channels, aggradated floodplains and modified hydroperiods. As a consequence, former extensive aquatic/terrestrial transition zones lack most of their basic ecological functions. Along large rivers in Europe and North America, various floodplain restoration or rehabilitation projects have been planned or realised in recent years. However, restoration ecology is still in its

infancy and the literature pertinent to river restoration is rather fragmented. (Semi-) aquatic components of floodplains, including secondary channels, disconnected and temporary waters as well as marshes, have received little attention, despite their significant contribution to biological diversity. Many rehabilitation projects were planned or realised without prior knowledge of their potential for success or failure, although, these projects greatly contributed to our present understanding of river–floodplain systems. River rehabilitation benefits from a consideration of river ecosystem concepts in quantitative terms, comparison with reference conditions, historical or others, and the establishment of interdisciplinary partnerships. We present examples from two large European rivers, the Danube and the Rhine, in which the role of aquatic connectivity has been extensively studied. The Danube delta with its diversity of floodplain lakes across an immense transversal gradient (up to 10 km) serves as a reference system for restoration projects along lowland sections of large rivers such as the Rhine in the Netherlands.

Bump, Joseph K. , Tischler, Keren B., Schrank, Amy J., Peterson, Rolf O. and Vucetich, John A., (2009) Large Herbivores and Aquatic-Terrestrial Links in Southern Boreal Forests, *Journal of Animal Ecology*, Vol. 78, No. 2 (Mar., 2009), pp. 338-345, <http://www.jstor.org/stable/27696373>

Concurrent measurement of population dynamics and associated spatio-temporal patterns of resource flow across aquatic—terrestrial boundaries are rare, yet necessary to understand the consequences of cross-habitat resource flux. Long-term study of the moose *Alces alces* (L.) population in Isle Royale National Park (Lake Superior, USA) provides an opportunity to examine the patterns of resource flux from aquatic to terrestrial habitats over 50 years. We analysed the spatio-temporal dynamics of aquatic-derived nitrogen (N) that moose transfer to terrestrial systems by using excretion models, foraging parameters, moose densities, and moose carcass locations (n = 3616) collected from 1958-2005. Results suggest that moose transfer significant amounts of aquatic-derived N to terrestrial systems, which likely increases terrestrial N availability in riparian zones. A seasonal increase in terrestrial N availability when moose are foraging on N-rich aquatic macrophytes would contrast with the depression of soil N mineralization previously attributed indirectly to moose. Aquatic foraging by moose and moose carcass locations are significantly clustered at multiple scales, indicating that grey wolves *Canis lupus* (L.) and moose can create concentrated areas of resource transfer due to clustered predation and foraging patterns. This study shows that patterns of faunal-mediated resource transfer can depend significantly on predator-prey dynamics, and that large predators in this system influence herbivore-controlled resource transfer between ecosystems. Given the circumpolar extent of moose, they constitute an important, unquantified aquatic-terrestrial resource vector in boreal systems.

Burnett, R. D., Gardali, T., & Geupel, G. R. (2005). Using songbird monitoring to guide and evaluate riparian restoration in salmonid-focused stream rehabilitation projects. *U S Forest Service General Technical Report PSW*, 191, 533–536.

A restoration effort, primarily focused on reducing stranding and improving passage of anadromous fish, has been undertaken along sections of lower Clear Creek, Shasta County, California. Similar projects are occurring throughout California and, indeed, all of North America. To monitor the effects of these efforts at Clear Creek we implemented a multi-

faceted songbird monitoring study. We have collected three years of data on abundance, diversity, reproductive success, and habitat associations of songbird populations at Clear Creek study plots where extensive watershed/salmonid restoration activities are in progress or slated to occur and at several reference sites where no restoration is planned. We used preliminary site-specific results and the California Partners in Flight Riparian Bird Conservation Plan to provide multi-level management recommendations. Monitoring songbirds on this and other restoration sites has proven a pragmatic approach on several levels. Songbird monitoring can (1) measure the effectiveness of restoration; (2) provide the necessary feedback for adaptive management; (3) guide restoration design by providing information on the health and habitat associations of the local bird populations; (4) be cost effective; and (5) provide education and outreach opportunities.

Buron, Timothy, Kretsinger, Carl. (1989). Restoration of severely eroded streambanks using tree revetments and willow revegetation on Diamond Creek, Caribou County, Idaho, *Practical Approaches to Riparian Resource Management: An Educational Workshop, 1989, May 8-11, 1989, Billings, Montana, United States, Bureau of Land Management, American Fisheries Society*, Pages 164.

For most Intermountain Region streams, the loss of stable riparian vegetation community types initiates a sequence of stream erosion resulting in development of steep, unstable cutbanks. As stable willow *Salix* spp. and sedge *Carex* spp. communities are altered to less stable vegetation types, the natural resistance to bank erosion is reduced. Resultant stream instability contributes to sedimentation and a shallower and wider water column. These factors often represent significant salmonid habitat quality reductions.

Camporeale, C., & Ridolfi, L. (2010). Interplay among river meandering, discharge stochasticity and riparian vegetation. *Journal of Hydrology*, 382, 138–144.

River sinuosity has an impact on riparian vegetation through different processes. The obvious one is the increment of the length of the riparian corridor due to meandering-induced river elongation. However, additional more subtle aspects occur, ascribable to topographic changes induced by meandering dynamics and to their impact on the stochastic structure of the river stage time series. It follows that the increment in vegetation biomass is not simply equal to the increment in the river length. In this work, we investigate this complex picture using suitable bio-geomorphological models through the study of an exemplifying case. This approach can suggest some novel tools for design the restoration of riparian corridors.

Capon, S. J., Chambers, L. E., MacNally, R., Naiman, R. J., Davies, P., Marshall, N., Williams, S. E. (2013). Riparian Ecosystems in the 21st Century: Hotspots for Climate Change Adaptation? *Ecosystems*, 16, 359–381.

Riparian ecosystems in the 21st century are likely to play a critical role in determining the vulnerability of natural and human systems to climate change, and in influencing the capacity of these systems to adapt. Some authors have suggested that riparian ecosystems are particularly vulnerable to climate change impacts due to their high levels of exposure and sensitivity to climatic stimuli, and their history of degradation. Others have highlighted the

probable resilience of riparian ecosystems to climate change as a result of their evolution under high levels of climatic and environmental variability. We synthesize current knowledge of the vulnerability of riparian ecosystems to climate change by assessing the potential exposure, sensitivity, and adaptive capacity of their key components and processes, as well as ecosystem functions, goods and services, to projected global climatic changes. We review key pathways for ecological and human adaptation for the maintenance, restoration and enhancement of riparian ecosystem functions, goods and services and present emerging principles for planned adaptation. Our synthesis suggests that, in the absence of adaptation, riparian ecosystems are likely to be highly vulnerable to climate change impacts. However, given the critical role of riparian ecosystem functions in landscapes, as well as the strong links between riparian ecosystems and human well-being, considerable means, motives and opportunities for strategically planned adaptation to climate change also exist. The need for planned adaptation of and for riparian ecosystems is likely to be strengthened as the importance of many riparian ecosystem functions, goods and services will grow under a changing climate. Consequently, riparian ecosystems are likely to become adaptation 'hotspots' as the century unfolds.

Carr W.W. (1985). Watershed Rehabilitation Options for Disturbed Slopes on the Queen Charlotte Islands, *Land Management Report, December. (1985). 36*, Minister of Forest, Victoria, BC, ISSN 0702-9861 <http://agris.fao.org/agris-search/search.do?recordID=US201300408968>

Surface erosion and mass wasting in forested watersheds can increase significantly following road development and logging. This is particularly true on steep forested slopes that receive a great deal of precipitation, such as those on the Queen Charlotte Islands. Through proper planning and the use of high construction standards, many of these problems can be alleviated, but not completely controlled. In addition, unforeseen problems that result in accelerated surface erosion and mass wasting may arise. For these reasons, the forest manager must have a variety of measures to either control or lessen erosion's impacts. This report reviews both prevention and rehabilitation techniques that may be of use in controlling erosion and/or alleviating further erosion damage on the Queen Charlotte Islands. To date, little erosion control or land rehabilitation work has been carried out on forested land on the Charlottes, and it is hoped that this report may provide the basis for future activities in this field.

Davies, Peter; Marshall, Nadine, Pittock, Jamie, Reid, Michael, Capon, Timothy, Douglas, Michael, Catford, Jane, Baldwin, Darren S., Stewardson, Michael, Roberts, Jane, Parsons Meg, Williams Stephen E. (2013). Climate Change Implications for River Restoration in Global Biodiversity Hotspots, *Ecosystems*, 16, No. 3, 359-381, <http://www.jstor.org/stable/23501465>

Global biodiversity hotspots contain exceptional concentrations of endemic species in areas of escalating habitat loss. However, most hotspots are geographically constrained and consequently vulnerable to climate change as there is limited ability for the movement of species to less hostile conditions. Predicted changes to rainfall and temperature will undoubtedly further impact on freshwater ecosystems in these hotspots. Southwestern Australia is a biodiversity hotspot and, as one of the first to experience significant climate

change, is an example and potentially a global bellwether for issues associated with river restoration. In this hotspot, current and predicted water temperatures may exceed thermal tolerances of aquatic fauna. Gondwanic aquatic fauna, characteristic of southwestern Australia, are typically cold stenotherms and consequently intolerant of elevated temperatures. The hotspot in southwestern Australia is geographically restricted being surrounded by ocean and desert, and many important national parks are located on the extreme south coast, where the landscape is relatively flat. Consequently, fauna cannot change their distribution southwards or with altitude as a response to increasing temperatures. Therefore, any mitigation responses need to be in situ to produce a suitable biophysical envelope to enhance species' resilience. This could be through "over restoration" by increased riparian replanting at a catchment scale. A rule-of-thumb of a 10% increase in riparian cover would be required to reduce water temperatures by 1, °C. These restoration techniques are considered applicable to other global biodiversity hotspots where geography constrains species' movement and the present condition is the desired restoration endpoint.

Chang, E.R., Jeffries L. and Carleton, T. J. Relationship between Vegetation and Soil Seed Banks in an Arctic Coastal Marsh, *Journal of Ecology*, Vol. 89, No. 3 (Jun., 2001), pp. 367-384, URL: <http://www.jstor.org/stable/3072282>

The effects of habitat degradation on the soil seed bank at La Pérouse Bay, Manitoba are described. Foraging by lesser snow geese leads to loss of vegetation, coupled with changes in soil abiotic conditions and an increase in salinity. The density of seeds and the relative abundance in the seed bank of species characteristic of undisturbed sites decrease following degradation, while the relative abundance of invasive species increases. Vegetation loss had the greatest impact on seed banks of stress-tolerant species and the least impact on species with many widely dispersed seeds. The above-ground vegetation and below-ground seed bank were less similar in undamaged plots than in disturbed plots. In spite of the low degree of similarity, redundancy analysis of the data indicated that approximately half of the variation in the soil seed bank could be explained by the vegetation data and vice versa. More recently degraded soils had richer soil seed banks than those from older disturbances. Site-specific factors not only influenced the species present but also the time lag between loss of vegetation and loss of the seed bank. Seed banks in these impacted and fragmented sites do not recover quickly. Seed banks in sandy beach-ridges were less affected by degradation due to the greater proportion of ruderals present in the original vegetation and the absence of the high soil salinities that are characteristic of degraded salt-marsh soils.

Christian-Smith, J., & Merenlender, A. M. (2010). The disconnect between restoration goals and practices: A case study of watershed restoration in the Russian River Basin, California. *Restoration Ecology*, 18, 95–102.

Over the past two decades, watershed restoration has dramatically increased internationally. California has been at the forefront, allocating billions of dollars to restoration activities through legislation and voter-approved bonds. Yet, the implications of restoration remain ambiguous because there has been little examination of restoration accomplishments and almost no analysis of the political context of restoration. This article addresses these gaps, utilizing a case study of the Russian River basin in Northern California. We identify trends that shed light on both the ecological and the political implications of restoration at a basin

scale by examining a database of 787 restoration projects implemented in the Russian River basin since the early 1980s. Although a total of over \$47 million has been spent on restoration in the basin, dominant forms of restoration are limited in scope to small-scale projects that focus on technical solutions to site-specific problems. The majority of restoration efforts are devoted to road repair, riparian stabilization, and in-stream structures, accounting for 62% of all projects. These types of projects do not address the broader social drivers of watershed change such as land and water uses. We suggest that restoration can become more effective by addressing the entire watershed as a combination of social and ecological forces that interact to produce watershed conditions.

Collins, K. E., Doscher, C., Rennie, H. G., & Ross, J. G. (2013). The effectiveness of riparian “restoration” on water quality - a case study of lowland streams in Canterbury, New Zealand. *Restoration Ecology*, 21, 40–48.

In New Zealand, around half of the lowland water bodies do not meet water quality standards, primarily due to widespread changes in land use. Riparian restoration has been occurring in New Zealand for over 30 years in an effort to minimize this impact, however, little monitoring of restoration effectiveness has been undertaken. This study evaluated the impact of riparian plantings on water quality of lowland streams in the Lake Ellesmere catchment. A paired-catchment design on four river reaches was used to compare restored riparian buffers with control sites upstream. Chemical water quality sampling was used in conjunction with a macro-invertebrate community assessment. Equivocal benefits of riparian restoration were observed, with improvements in some variables but not in others. Riparian restoration had a positive effect on water quality in terms of increasing dissolved oxygen and decreasing turbidity. However, conductivity increased at planted sites and no changes were observed in other variables. These findings may be affected by the insufficient width of all four buffers, and gaps in the buffer system contributing to poor water quality. Although variable responses were seen in invertebrate community composition, this research suggests that even narrow planted buffer strips may be effective in improving some water quality parameters. The overall mixed results present a fair assessment of the benefits of riparian restoration that may be expected within a relatively short time following vegetation establishment. Even when no baseline data have been established prior to restoration, this research showed monitoring can demonstrate the effectiveness of riparian restoration.

Corenblit, Dov, Steiger, Johannes; Gurnell, Angela M.; Naiman, Robert J.; Sykes, Martin. (2009). Plants Intertwine Fluvial Landform Dynamics with Ecological Succession and Natural Selection: A Niche Construction Perspective for Riparian Systems. *Global Ecology and Biogeography*, 18, No. 4, 507-520. <http://www.jstor.org/stable/40205700>.

The purpose of this document is to contribute to the development of a macro-evolutionary framework for riparian systems, reinforcing conceptual linkages between earth surface processes and biological and ecological processes. Location: Riparian systems. Methods: Literature review leading to an original proposition for perceiving the functioning of riparian systems in a new and different way. Results: Riparian systems provide diverse landforms, habitats and resources for animals and plants. Certain organisms, defined as 'ecosystem engineers', significantly create and modify the physical components of riparian systems.

Many studies have highlighted such engineering effects by animals on riparian systems, but the identification and understanding of the effects and responses of plants within fluvial corridors have emerged only recently. The modulation of matter, resources and energy flows by engineering plants helps establish characteristic sequences of fluvial landform creation and maintenance associated with synergetic ecological successions. We relate this process to the concept of niche construction, developed mainly by evolutionary biologists. Feedbacks between adaptive responses of riparian plants to flow regime and adjusting effects on bio-stabilization and bio-construction are discussed in the context of niche construction at the scale of ecological succession and the evolution of organisms. Main conclusions: Our conceptualization forges an integrated approach for understanding vegetated fluvial systems from a macro-evolutionary perspective, for elucidating riparian ecosystem dynamics and potentially for establishing long-term stream conservation and restoration strategies.

Craig, L. S., Palmer, M. A., Richardson, D. C., Filoso, S., Bernhardt, E. S., Bledsoe, B.P., Wilcock, P. R. (2008). Stream restoration strategies for reducing river nitrogen loads. *Frontiers in Ecology and the Environment*. 21, Issue 6, 529-538.

Despite decades of work on implementing best management practices to reduce the movement of excess nitrogen (N) to aquatic ecosystems, the amount of N in streams and rivers remains high in many watersheds. Stream restoration has become increasingly popular, yet efforts to quantify N-removal benefits are only just beginning. Natural resource managers are asking scientists to provide advice for reducing the downstream flux of N. Here, we propose a framework for prioritizing restoration sites that involves identifying where potential N loads are large due to sizeable sources and efficient delivery to streams, and when the majority of N is exported. Small streams (1st–3rd order) with considerable loads delivered during low to moderate flows offer the greatest opportunities for N removal. We suggest approaches that increase in-stream carbon availability, contact between the water and benthos, and connections between streams and adjacent terrestrial environments. Because of uncertainties concerning the magnitude of N reduction possible, potential approaches should be tested in various landscape contexts; until more is known, stream restoration alone is not appropriate for compensatory mitigation and should be seen as complementary to land-based best management practices.

Davies, P. M. (2010). Climate Change Implications for River Restoration in Global Biodiversity Hotspots. *Restoration Ecology*, 18, 261–268.

Global biodiversity hotspots contain exceptional concentrations of endemic species in areas of escalating habitat loss. However, most hotspots are geographically constrained and consequently vulnerable to climate change as there is limited ability for the movement of species to less hostile conditions. Predicted changes to rainfall and temperature will undoubtedly further impact on freshwater ecosystems in these hotspots. Southwestern Australia is a biodiversity hotspot and, as one of the first to experience significant climate change, is an example and potentially a global bellwether for issues associated with river restoration. In this hotspot, current and predicted water temperatures may exceed thermal tolerances of aquatic fauna. Gondwanic aquatic fauna, characteristic of southwestern Australia, are typically cold stenotherms and consequently intolerant of elevated temperatures. The hotspot in southwestern Australia is geographically restricted being

surrounded by ocean and desert, and many important national parks are located on the extreme south coast, where the landscape is relatively flat. Consequently, fauna cannot change their distribution southwards or with altitude as a response to increasing temperatures. Therefore, any mitigation responses need to be in situ to produce a suitable biophysical envelope to enhance species' resilience. This could be through "over restoration" by increased riparian replanting at a catchment scale. A rule-of-thumb of a 10% increase in riparian cover would be required to reduce water temperatures by 1, circC. These restoration techniques are considered applicable to other global biodiversity hotspots where geography constrains species' movement and the present condition is the desired restoration endpoint.

Dosskey, M. G., Vidon, P., Gurwick, N. P., Allan, C. J., Duval, T. P., & Lowrance, R. (2010). The Role of Riparian Vegetation in Protecting and Improving Chemical Water Quality in Streams. *JAWRA Journal of the American Water Resources Association*, 46, 261–277.

We review the research literature and summarize the major processes by which riparian vegetation influences chemical water quality in streams, as well as how these processes vary among vegetation types, and discuss how these processes respond to removal and restoration of riparian vegetation and thereby determine the timing and level of response in stream water quality. Our emphasis is on the role that riparian vegetation plays in protecting streams from nonpoint source pollutants and in improving the quality of degraded stream water. Riparian vegetation influences stream water chemistry through diverse processes including direct chemical uptake and indirect influences such as by supply of organic matter to soils and channels, modification of water movement, and stabilization of soil. Some processes are more strongly expressed under certain site conditions, such as de-nitrification where groundwater is shallow, and by certain kinds of vegetation, such as channel stabilization by large wood and nutrient uptake by faster-growing species. Whether stream chemistry can be managed effectively through deliberate selection and management of vegetation type, however, remains uncertain because few studies have been conducted on broad suites of processes that may include compensating or reinforcing interactions. Scant research has focused directly on the response of stream water chemistry to the loss of riparian vegetation or its restoration. Our analysis suggests that the level and time frame of a response to restoration depends strongly on the degree and time frame of vegetation loss. Legacy effects of past vegetation can continue to influence water quality for many years or decades and control the potential level and timing of water quality improvement after vegetation is restored. Through the collective action of many processes, vegetation exerts substantial influence over the well-documented effect that riparian zones have on stream water quality. However, the degree to which stream water quality can be managed through the management of riparian vegetation remains to be clarified. An understanding of the underlying processes is important for effectively using vegetation condition as an indicator of water quality protection and for accurately gauging prospects for water quality improvement through restoration of permanent vegetation.

Dufour, S., Bernez, I., Betbeder, J., Corgne, S., Hubert-Moy, L., Nabucet, J., Trollé, C. (2013). Monitoring restored riparian vegetation: how can recent developments in remote sensing sciences help? *Knowledge and Management of Aquatic Ecosystems*, Issue 410, 10 pages.

Riparian vegetation restoration projects require appropriate tools to monitor actions efficiency. On a large scale remote sensing approaches can provide continuous and detailed data to describe riparian vegetation. In this paper, we illustrated recent developments and perspectives for riparian vegetation monitoring purposes through three examples of image sources: Light Detection And Ranging (LiDAR), radar and Unmanned Aerial Vehicle (UAV) images. We notably focused on the potential of such images to provide 3D information for narrow strips of riparian vegetation with high temporal resolution to allow fine monitoring following restoration program. LiDAR data allows canopy structure identification with a high accuracy level and automatic classifications for heterogeneous riparian corridors. Radar images allow a good identification of riparian vegetation but also of the structure and phenology of vegetation through time with an analysis of the Shannon entropy of the signal. The UAV system used here is a very flexible approach that can easily provide RGB mosaic but also a local digital surface model with very high spatial resolution. Lastly, we discuss the advantages and limitations of each approach from

Dynesius, Mats, Jansson, Johansson Roland E. and Nilsson, Christer, (2004) Intercontinental Similarities in Riparian-Plant Diversity and Sensitivity to River Regulation, *Ecological Applications*, 14, No. 1 (Feb., 2004), pp. 173-191, <http://www.jstor.org/stable/4493529>

We asked whether assemblages of species with separate evolutionary histories differed in their response to similar human interventions. We assessed this by comparing the response of riparian plant communities to river regulation on two different continents. We compared free-flowing and regulated rivers between boreal parts of North America (Alberta and British Columbia) and Europe (Sweden), using a standardized sampling protocol and the same field staff on both continents. Although the two regions shared few species, both riparian plant-species diversity along free-flowing rivers and the response to different kinds of flow regulation were similar between the continents. The number of riparian-plant species and their amount of cover differed among types of water-level regime, but the continental affiliation of a river-margin site did not statistically explain any of the variation. Within continents, the local flora of the regulated river-margin sites was largely similar in species composition to the free-flowing ones, but the sites along storage reservoirs were more species-poor. The similarity in the response to regulation between the continents suggests that general guidelines for rehabilitation of degraded boreal rivers are a realistic goal. The number of species and genera, plant cover, and species numbers in most trait groups (classified according to growth form and life span) were similar between free-flowing river margins in Europe and North America. Moreover, the regional native species pools of northern Sweden and Alberta were similar in size and composition of species groups, despite the fact that only 27% of the species in Alberta were found in northern Sweden. This is presumably because the floras share a common Tertiary origin and because the regions have had largely similar late-Tertiary and Quaternary histories. The most pronounced difference between the continents was that we found no exotic species on the 183 Swedish river-margin sites, whereas 9% of the species found in all 24 North American plots taken together were exotics. All North American exotics found have occurred in Europe since prehistoric times, and the difference in exotic richness most likely reflects a difference in the number of species humans have transferred from one continent to another, rather than a difference in invasibility between the regions.

Johanna Engström; Christer Nilsson; Roland Jansson, (2009), Effects of Stream Restoration on Dispersal of Plant Propagules, *Journal of Applied Ecology*, Vol. 46, No. 2, 397-405, <http://www.jstor.org/stable/27695962>

Species immigration is vital for the success of restoring degraded ecosystems, but the effectiveness of enhancing dispersal following restoration is seldom evaluated. Running water is an important vector for plant dispersal. Frequency and duration of floods and channel-network complexity are important factors influencing propagule dispersal. We studied the efficiency of propagule retention following restoration by releasing propagule mimics and by placing propagule traps in the riparian zone. 3. Retention of propagule mimics was highest in sites restored with boulders and large wood. Retention occurred at both high and low flows but was most efficient during low flows when mimics were trapped by boulders and wood. Waterborne propagules ending up at such sites are unlikely to establish unless they can reach the riparian zone later. At high flows, floating propagules are more likely to reach riparian areas suitable for establishment. According to propagule traps placed at various levels of the riparian zone, deposition of plant propagules and sediments did not increase in restored sites. 4. Synthesis and applications. Our study not only demonstrates that restoration of channel complexity through replacement of boulders and wood can enhance retention of plant propagules, but also it highlights the importance of understanding how restoration effects vary with flow. Most streams are restored to function optimally during median or average flows, whereas communities often are controlled by ecological processes acting during extreme flow events. We advocate that stream restoration should be designed for optimal function during those discharges under which the ecological processes in question are most important, which in this case is, during high flow.

France, R.L., Macroinvertebrate Colonization of Woody Debris in Canadian Shield Lakes following Riparian Clearcutting. (1997). *Conservation Biology*, 11, No. 2, 513-521, <http://www.jstor.org/stable/2387624>

Deployment of litter-fall traps revealed that clear-cut logging of boreal riparian forest in northwestern Ontario, Canada resulted in a dramatic shift from once dominant conifers to regrowth composed largely of deciduous trees and reduced the allochthonous inputs of small woody debris to lake littoral zones by over 90%. Due to the rarity of macrophytes in these oligotrophic lakes, littoral macroinvertebrates were found to actively colonize woody debris placed within mesh litter bags. The recalcitrant nature of small woody debris in these lakes (average median persistence time of about 5 years estimated from mass loss data) indicates, however, that this important habitat resource will probably never completely disappear in relation to its projected rate of resupply during post-disturbance forest regeneration. Colonization rates of twigs and bark contained within the litter bags were not found to differ between coniferous and deciduous species. This indicates that macro-invertebrates in these boreal lakes are merely opportunistic colonizers of woody debris, probably for its use as either a biofilm substrate or a predation refuge. As a result, shifts in tree species composition following riparian clear-cutting should not detrimentally affect the taxa richness or organism abundance of aquatic macro-invertebrates in these lakes.

Fredriksen, R.L. Erosion and sedimentation following road construction and timber harvest on unstable soils in three small western Oregon watersheds. (1970). [Research Papers. Pacific](#)

Describes a study made in 1960-69 in three catchment areas [cf. FA 32 No. 76], that had been patch-logged (a), clear-felled (b), or left undisturbed (c), in Douglas Fir forest on soil derived from tuff and breccia. Logs were removed from (a) by a system of roads covering ca. 6% of the catchment area, and from (b) by skyline logging equipment. Tables and graphs show that sedimentation from (a) averaged over 100 times, and from (b) over 3 times, that from (c). Landslides were the main source of increased sedimentation on (a), and these were most frequent where roads crossed stream channels.

Fullerton, A. H., Beechie, T. J., Baker, S. E., Hall, J. E., & Barnas, K. A. (2006). Regional patterns of riparian characteristics in the interior Columbia River basin, Northwestern USA: applications for restoration planning. *Landscape Ecology*.

Recent declines in anadromous Pacific salmonids (*Oncorhynchus* spp.) have been attributed, in part, to degradation of freshwater habitat. Because riparian areas directly affect in-stream habitat, assessing riparian characteristics is essential for predicting salmon habitat quality and for prioritizing restoration projects. We quantified land use modification of anadromous fish-bearing streams in the interior Columbia River basin at multiple resolutions. We identified riparian areas in several land use and land cover classes using remotely sensed data. We then interpreted aerial photographs at random locations within each class to quantify riparian modifications at a local (stream reach) scale. Riparian areas in agricultural and urban areas were significantly narrower (~30 m, median) than those in forested or shrub/grass areas (~70 m). The largest proportion of modified riparian areas occurred in low-gradient streams with floodplains in semi-arid ecoregions. Riparian vegetation in these areas is unlikely to provide adequate in-stream functions, making these areas a natural starting point for restoration prioritization. We investigated how existing riparian restoration projects were spatially related to riparian land use and found that restoration effort varied among sub-watersheds. Effective strategies for restoring high quality salmon habitat will be watershed-specific and must restore natural watershed processes. By using a hierarchical analysis to identify regional strategies, restoration or conservation activity can be focused in specific basins and thereby increase the likelihood that efforts will significantly improve habitat conditions for listed salmonids.

Gardali, T., & Holmes, A. L. (2011). Maximizing benefits from riparian revegetation efforts: local- and landscape-level determinants of avian response. *Environmental Management*, 48, 28–37.

With limited financial resources available for habitat restoration, information that ensures and/or accelerates success is needed to economize effort and maximize benefit. In the Central Valley of California USA, riparian habitat has been lost or degraded, contributing to the decline of riparian-associated birds and other wildlife. Active restoration of riparian plant communities in this region has been demonstrated to increase local population sizes and species diversity of land birds. To evaluate factors related to variation in the rate at which bird abundance increased after restoration, we examined bird abundance as a function of local (restoration design elements) and landscape (proportion of riparian vegetation in the landscape and riparian patch density) metrics at 17 restoration projects within five project

areas along the Sacramento River. We developed a priori model sets for seven species of birds and used an information theoretic approach to identify factors associated with the rate at which bird abundance increased after restoration. For six of seven species investigated, the model with the most support contained a variable for the amount of riparian forest in the surrounding landscape. Three of seven bird species were positively correlated with the number of tree species planted and three of seven were positively correlated with the planting densities of particular tree species. Our results indicate that restoration success can be enhanced by selecting sites near existing riparian habitat and planting multiple tree species. Hence, given limited resources, efforts to restore riparian habitat for birds should focus on landscape-scale site selection in areas with high proportions of existing riparian vegetation.

Giller, P. S. (2005a). River restoration: seeking ecological standards. Editor's introduction. *Journal of Applied Ecology*, 42, 201–207.

In the face of continuing anthropogenic stressors to freshwater systems world-wide, the natural resilience and resistance of the freshwater ecosystems that enables them to cope with or recover rapidly from certain levels of perturbation is under significant threat. In many systems, the changes brought about through human activities have significantly altered the physical habitat and ecological functioning of the natural systems. Given the importance of freshwater systems in the provision of ecological services and diverse habitats for a huge range of species, there is a clear need for restoration that can maintain sustainable ecological services whilst reinstating ecosystem function and habitat range. While restoration has been attracting huge financial investment in recent times, to date there has been little or no consensus as to what constitutes successful ecological restoration. The studies highlighted in this Special Profile attempt to meet this challenge. The Forum paper establishes a set of criteria or standards against which restoration projects can be evaluated, and these criteria are discussed by both practitioners and researchers in two Comment papers. The five criteria proposed in the Forum paper include the establishment of a dynamic ecological endpoint to the restoration, providing for a 'guiding image' of a healthier river, and an improvement in the river's ecological condition, that ideally leads to a more self-sustaining and resilient system. No lasting harm should be inflicted on the system during the restoration, and pre- and post-assessment and monitoring must be incorporated into the overall restoration project. An additional sixth criterion is proposed in one of the Comment papers whereby a description or prediction of the ecological mechanisms should be determined through which the intended restoration strategy will achieve its goals. The kinds of mechanisms that might be involved are explored in three research articles in the Special Profile, centred on river systems that have been subject to regulation or channelization. The mitigation of the effects of river regulation measures and the successful restoration of floodplain ecosystems has a focus on re-establishing river flow dynamics (temporal heterogeneity) and connectivity of the river with the floodplain. Restoration of channelized systems is centred on increasing the structural (spatial) heterogeneity of the system. Synthesis and applications: River restoration is a world-wide phenomenon of growing importance as we attempt to redress the problems that have arisen from our use and misuse of freshwater habitats and resources. The adoption of standards for ecologically successful river restoration promoted by Palmer et al. (2005), along with the clarifications raised in the Comment papers, will go a long way towards meeting this objective. There is a clear responsibility for funding agencies to undertake

meaningful monitoring of restoration projects, not only to provide information on the effectiveness of the restoration in ecological terms, but also to provide much needed data to help establish further the science of restoration. The objective of this significant initiative is eventually to achieve approval of the standards by the sponsoring/funding agencies of restoration, by the practitioner community that carries out the restoration, and by the scientific research community. This will require much greater interaction between ecologists, the larger academic community and the practitioners, with the common goal of implementing more ecologically effective restoration projects, a goal that must also be embraced by the restoration project sponsors and regulators.

Golet, G. H., Gardali, T., Hunt, J. W., Koenig, D. A., & Williams, N. M. (2011). Temporal and Taxonomic Variability in Response of Fauna to Riparian Restoration. *Restoration Ecology*, 19, 126–135.

Evaluating the success of restoration projects requires well-designed studies. Among the decisions that need to be made are what taxonomic groups to study and when to conduct the monitoring. To explore how these decisions can influence assessments of restoration success, we examined species richness and composition data collected over several years on different terrestrial fauna (land birds, rodents, bees, and beetles) at Sacramento River restoration and remnant riparian sites. Our selection of study organisms enabled us to ask whether variability in species richness among restoration sites is less for vagile taxa than for sedentary taxa, and if invertebrates display greater variability among sites than vertebrates. Our results demonstrate that responses to restoration can vary depending upon the season when it is assessed, and the taxa that are studied. For all taxa except bees, there was considerable variability in the relative performance of taxa at restoration sites from one sampling date to the next, such that the relative ranking of the sites often changed dramatically. Comparisons of β -diversity (variability in species richness across sites) revealed that certain taxonomic groups were more spatially variable in their response to restoration than others. Among vertebrates, sedentary taxa (rodents) had significantly higher variability in species richness across sites than highly vagile taxa (birds); however, no such pattern was observed for invertebrates. Overall, vertebrates had lower variability than invertebrates, suggesting that evaluations of restoration success based on a few better-known taxonomic groups (e.g., birds, rodents) may be inadequate to represent the biodiversity response of other groups (e.g., insects).

Gollan, J. R., Bruyn, L. L. De, Reid, N., Smith, D., & Wilkie, L. (2011). Can ants be used as ecological indicators of restoration progress in dynamic environments? A case study in a revegetated riparian zone. *Ecological Indicators*, 11, 1517–1525.

Ant assemblages are focal ecological indicators of progress in mine-site restoration, often showing increasing species richness with restoration age. Certain functional groups also behave in predictable ways in response to disturbance and changes in the environment. Whether these ant responses can be applied to other types of restoration and ecosystems is unknown, especially in dynamic environments and where gradients may not be as severe as in mine-site restoration. Ant assemblages would be expected to perform poorly as ecological indicators in dynamic environments because such environs are subject to periodic disturbance of important habitat features. Indeed, periodic disturbance may limit the

predictive power of any ecological indicator. In this study, we trapped ants on two separate occasions to compare ant assemblages among four riparian habitat types (Unplanted grassland, Young revegetation, Older revegetation and Mature woodland). These habitat types were assumed to represent progressive stages of restoration. In contrast to the findings of others, species richness was variable among replicate locations of the same habitat type, and did not differ among the four habitat types. Also in contrast to what others have found for functional groups, dolichoderines were equally abundant in all habitat types and did not decrease in abundance with vegetation maturity. While generalized myrmicines and opportunists became more common with maturation of the vegetation, they did not replace dolichoderines as the most common ants. Surprisingly, the relative abundance of Subordinate Camponotini, a functional group considered to be of limited use in discriminating structural types, increased across the restoration gradient. There were also fairly distinct species assemblages associated with unplanted grassland and mature woodland. Communities in revegetated habitats were intermediate of these extremes, suggesting there is a level of predictiveness to their response to revegetation in this system. While species richness and a functional group approach would be of little use in this environment, species composition would provide a useful gauge of restoration progress. Ant species richness and functional group metrics have repeatedly been advocated as ecological indicators. Given our results, we caution against the blind application of metrics that have not been validated in the context in which they are to be applied.

Goodwin, C. N., Hawkins, C. P., & Kershner, J. L. (1997). Riparian restoration in the western United States: overview and perspective. *Restoration Ecology*, 5, 4–14.

This historical and conceptual overview of riparian ecosystem restoration discusses how riparian ecosystems have been defined, describes the hydrologic, geomorphic, and biotic processes that create and maintain riparian ecosystems of the western USA, identifies the main types of anthropogenic disturbances occurring in these ecosystems, and provides an overview of restoration methods for each disturbance type. We suggest that riparian ecosystems consist of two zones: Zone I occupies the active floodplain and is frequently inundated and Zone II extends from the active floodplain to the valley wall. Successful restoration depends on understanding the physical and biological processes that influence natural riparian ecosystems and the types of disturbance that have degraded riparian areas. Thus we recommend adopting a process-based approach for riparian restoration. Disturbances to riparian ecosystems in the western USA result from stream-flow modifications by dams, reservoirs, and diversions; stream channelization; direct modification of the riparian ecosystem; and watershed disturbances. Four topics should be addressed to advance the state of science for restoration of riparian ecosystems: (1) interdisciplinary approaches, (2) a unified framework, (3) a better understanding of fundamental riparian ecosystem processes, and (4) restoration potential more closely related to disturbance type. Three issues should be considered regarding the cause of the degraded environment: (1) the location of the causative disturbance with respect to the degraded riparian area, (2) whether the disturbance is ongoing or can be eliminated, and (3) whether or not recovery will occur naturally if the disturbance is removed.

Gumiero, Bruna, Mant, Jenny, Hein, Thomas, Elso, Josu, Boz, Bruno. (2013). Linking the restoration of rivers and riparian zones/wetlands in Europe: Sharing knowledge through case studies. *Ecological Engineering*, 56, 36–50.

Deployment of litterfall traps revealed that clearcut logging of boreal riparian forest in northwestern Ontario, Canada resulted in a dramatic shift from once dominant conifers to regrowth composed largely of deciduous trees and reduced the allochthonous inputs of small woody debris to lake littoral zones by over 90%. Due to the rarity of macrophytes in these oligotrophic lakes, littoral macro-invertebrates were found to actively colonize woody debris placed within mesh litter bags. The recalcitrant nature of small woody debris in these lakes (average median persistence time of about 5 years estimated from mass loss data) indicates, however, that this important habitat resource will probably never completely disappear in relation to its projected rate of resupply during post-disturbance forest regeneration. Colonization rates of twigs and bark contained within the litter bags were not found to differ between coniferous and deciduous species. This indicates that macro-invertebrates in these boreal lakes are merely opportunistic colonizers of woody debris, probably for its use as either a biofilm substrate or a predation refuge. As a result, shifts in tree species composition following riparian clear-cutting should not detrimentally affect the taxa richness or organism abundance of aquatic macro-invertebrates in these lakes.

Gray, D.H. and A.T. Leiser. (1982). Biotechnical Slope Protection and Erosion Control. *Van Nostrand Reinhold Company Inc.* Scarborough, Ontario, 271 pp. (reprinted by Krieger Publishing Co. Malabar, Florida, 1989).

This classic text on bioengineering shows techniques of bioengineering and horticulture to protect slopes from collapsing. The general principles and advantages of biotechnical slope protection systems are discussed. Contour wattling; brush layering, live stacking and brush matting are described. Use of slope planting in conjunction with earth retaining structures is discussed. Engineering design and plant material guidelines are included.

Gray, Donald H. and Sotir, Robbin B. (1996), Biotechnical and Soil Bioengineering Slope Stabilization: A Practical Guide for Erosion Control, *John Wiley & Sons*, 378 pages

This is the first comprehensive, practical book to cover all aspects of the selection, construction, and installation of soil bioengineering and biotechnical slope protection used for protecting slopes from erosion and mass wasting. Illustrated with more than 150 photographs and supplemented with scores of charts and tables, this book covers the entire subject from general principles and background on the nature of soil erosion and mass movement to detailed information on root strengths, treatment selection, unit costs, critical tractive stresses, methods for harvesting and handling live cuttings, and more.

Four illustrated case studies, each addressing a different set of problems and solutions, demonstrate the application of particular technologies and the site investigation, planning, scheduling, and organization required to complete these projects successfully. This unique reference handbook reviews the horticultural and engineering underpinnings for biotechnical and soil engineering treatments, documents and explains the role of woody plants in

stabilizing slopes against both surficial erosion and mass movement, provides details on a broad range of soil bioengineering methods, including live staking, live fascines, brush layering, live crib walls, branch packing, and live slope gratings. Descriptions of various biotechnical methods and materials, including the incorporation of vegetation in erosion control blankets, flexible mats, cellular revetments (geocells), rock armor (rip rap), and gabion and open-front crib walls are provided. The findings of the National Science Foundation-sponsored workshop to assess the state of the art and determine research needs is summarized.

Gunderson, Per, Laurén, Ari, Finér, Leena, Ring, Eva, Koivusalo, Harri, Sætersdal, Magne, Weslien, Jan-Olov, Bjarni D., Sigurdsson, Högbom, Lars, Laine, Jukka and Hansen, Karin, (2010), Environmental Services Provided from Riparian Forests in the Nordic Countries, *Ambio*, Vol. 39, No. 8 (December 2010), pp. 555-566, <http://www.jstor.org/stable/40928412>

Riparian forests (RF) growing along streams, rivers and lakes comprise more than 2% of the forest area in the Nordic countries (considering a 10 m wide zone from the water body). They have special ecological functions in the landscape. They receive water and nutrients from the upslope areas, are important habitats for biodiversity, have large soil carbon stores, but may emit more greenhouse gases (GHG) than the uplands. In this article, we present a review of the environmental services related to water protection, terrestrial biodiversity, carbon storage and greenhouse gas dynamics provided by RF in the Nordic countries. We discuss the benefits and trade-offs when leaving the RF as a buffer against the impacts from upland forest management, in particular the impacts of clear cutting. Forest buffers are effective in protecting water quality and aquatic life, and have positive effects on terrestrial biodiversity, particularly when broader than 40 m, whereas the effect on the greenhouse gas exchange is unclear.

Hagar, Joan C., (1999) Influence of Riparian Buffer Width on Bird Assemblages in Western Oregon *The Journal of Wildlife Management*, Vol. 63, No. 2 (Apr., 1999), pp. 484-496, <http://www.jstor.org/stable/3802633>

The goals of current management practices in riparian areas in the Pacific Northwest include protecting and maintaining habitat for terrestrial wildlife. However, little is known about the use of riparian buffers by terrestrial wildlife, particularly how buffer width may affect abundance and species composition of wildlife communities. In this study, I compared bird assemblages in logged and unlogged riparian areas along headwater streams and assessed the relations between bird abundance and riparian buffer width. The abundances of 4 species of forest-associated birds that were more abundant in unlogged than in logged headwater riparian stands (Pacific-slope flycatcher [*Empidonax difficilis*], brown creeper [*Certhia americana*], chestnut-backed chickadee [*Poecile rufescens*], winter wren [*Troglodytes troglodytes*]) increased with increasing width of riparian buffers. However, 4 other species that also were more abundant in unlogged than logged riparian stands (Hammond's flycatcher [*Empidonax hammondi*], golden-crowned kinglet [*Regulus satrapa*], varied thrush [*Ixoreus naevius*], hermit warbler [*Dendroica occidentalis*]) were rarely observed in even the widest buffers sampled (40-70 m on 1 side of the stream). Although riparian buffers along headwater streams are not expected to support all bird species found in unlogged riparian areas, they are likely to provide the most benefit for forest-associated bird species if

they are >40 m wide, and density of large trees within buffers is not reduced by harvesting.

Harris, R. R., Hopkinson, P., McCaffrey, S., & Huntsinger, L. (1997). Comparison Of a Geographical Information System Versus Manual Techniques For Land Cover Analysis In a Riparian Restoration Project. *Journal of Soil and Water Conservation*, 52, 112–117.

Few studies have addressed the benefits and costs of computerized geographical information systems (GIS) as compared to manual methods of cartographic analysis. However, GIS require substantial investment in equipment and personnel which is of particular importance to small or financially strapped resource management agencies. In this case study, land cover maps created as part of a riparian restoration research project were used to compare the time costs involved in calculating land cover areas with a GIS and manually with a planimeter and dot grid. Simple modeling of riparian forest restoration potential was also performed to investigate the GIS value for restoration planning. While estimates of land cover areas were similar for the two methods, GIS time costs were many times higher than manual technique time costs. Development of even a simple modeling procedure for restoration planning proved difficult and time consuming. Modeling results, although useful, also require validation. As the complexity of modeling increases, the need for technical expertise and analyst time increases without negating the need for validation. Natural resource managers should carefully evaluate long term benefits and costs before adopting a GIS for riparian restoration planning. Hawkins, C. P., Bartz, K. L., & Neale, C. M. U. (1997). Vulnerability of riparian vegetation to catastrophic flooding: Implications for riparian restoration. *Restoration Ecology*, 5, 75–84.

K. A. Harper; S. E. Macdonald, (2001), Structure and Composition of Riparian Boreal Forest: New Methods for Analyzing Edge Influence, *Ecology*, Vol. 82, No. 3 (Mar., 2001), pp. 649-659, Ecological Society of America, <http://www.jstor.org/stable/2680186>

Riparian ecotones at lakeshore edges are prominent features on the heterogeneous boreal forest landscape. We introduce a new method (the critical values approach), which incorporates inherent variability in interior forest, to quantify distance of edge influence at lakeshore forest edges. We use this method to examine the variation in forest structure and composition along the lakeshore forest edge-to-interior gradient in the mixed-wood boreal forest. Our objectives were: (1) to quantify distance of edge influence for forest structure and composition at lakeshore forest edges; and (2) to investigate spatial pattern in vegetation along the edge-to-interior gradient. Trees, coarse woody material, saplings, shrubs, and herbs were sampled in plots at varying distances along 200-m transects established perpendicular to lakeshore forest edges. Distance of edge influence was determined by comparing mean values at different positions along the transect to critical values established from a randomization test of interior forest data. The spatial pattern of four selected species along the edge-to-interior gradient was assessed using split moving window analysis and wavelet analysis. The results suggest that a distinct lakeshore forest edge community exists. This community was ~40 m wide and was characterized by greater structural diversity, larger amounts of coarse woody material, and more saplings and mid-canopy trees than interior forest. Distance of edge influence for understory composition was generally greater than for forest structure. Patterns of response for different species along the edge-to-interior gradient

were related to shade tolerance. Lakeshore forest edges are distinct landscape elements, but their prominence depends on the reference forest, species, and scale.

Helfield, James M. and Naiman, Robert J. (2006). Keystone Interactions: Salmon and Bear in Riparian Forests of Alaska. *Ecosystems*, Vol. 9, No. 2 (Mar., 2006), pp. 167-180, <http://www.jstor.org/stable/25470328>

Because of their role in transporting nutrients from the ocean to river and riparian ecosystems, Pacific salmon (*Oncorhynchus* spp.) and brown bear (*Ursus arctos*) have been described as keystone species and mobile links, although few data are available to quantify the importance of this interaction relative to other nutrient vectors. Application of a mass balance model to data from a southwestern Alaskan stream suggests that nitrogen (N) influx to the riparian forest is significantly increased in the presence of both salmon and bear, but not by either species individually. The interactions of salmon and bear may provide up to 24% of riparian N budgets, but this percentage varies in time and space according to variations in salmon escapement, channel morphology and watershed vegetation characteristics, suggesting interdependence and functional redundancy among N sources. These findings illustrate the complexity of interspecific interactions, the importance of linkages across ecosystem boundaries and the necessity of examining the processes and interactions that shape ecological communities, rather than their specific component parts.

Hubble, T.C.T., Docker, B.B. and Rutherford I.D., The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice, *Ecological Engineering*, Volume 36, Issue 3, March 2010, Pages 292-304

Riverside vegetation is a significant factor influencing the occurrence and progress of streambed and riverbank erosion. Recent riparian management practice in Australia has focussed on re-establishing or maintaining native riparian vegetation in order to control or prevent erosion as well as regenerate or preserve the complex variety of in-stream and riverside habitats. This work presents an integrated review of field and experimental studies conducted in eastern Australia that evaluate native vegetation's role in mass failure of riverbanks. Several results of these studies have general application and include the following: (1) The presence of riparian forest on riverbanks significantly reduces the likelihood of erosion by mass failure due to reinforcement of riverbank soils by tree roots and this reduced likelihood of mass failure enables a narrower channel cross-section than would otherwise be the case for many Australian coastal streams. (2) A number of Australian tree species have apparently evolved roots that seek the permanent, summer water table in order to survive prolonged dry spells, these root systems are particularly effective in mass failure mitigation due to rooting depths that are commonly greater than 5 m and are sometimes well in excess of 20 m. (3) The so-called "Root-Area-Ratio method" of calculating the shear strength of root-reinforced soil using root tensile strength data and Waldron's [Waldron, L.J., 1977. The shear resistance of root-permeated homogenous and stratified soil. *J. Soil Sci. Soc. Am.* 41, 843–849] and Wu et al's [Wu, T.H., McKinnell, W.P., Swanston, D.N., 1979. Strength of tree roots and landslides on Prince of Wales Island, Alaska. *Can. Geotech. J.* 16, 19–33] simple root model leads to significant overestimation of the actual root-reinforcement due to (a) breakage or pull-out of roots that taper and narrow

beneath the shear plane such that individual roots do not achieve the tensile strength calculated on the basis of root diameter at the shear plane; and/or (b) the fact that the soil mass fails progressively along the length of potential shear plane rather instantaneously across the entire shear plane.

Hyatt, T. L., Waldo, T. Z., & Beechie, T. J. (2004). A Watershed Scale Assessment of Riparian Forests, with Implications for Restoration. *Restoration Ecology*, 12, 175–183.

A combination of air-photo interpretation, field data, and Geographic Information System (GIS) analysis was used to map riparian areas that are likely to provide wood and shade to small- and medium-sized streams and where, conversely, restoration might be most beneficial. The analysis encompassed all salmonid-bearing waters of the Nooksack River basin, in northwest Washington State, plus small tributaries that were thought to contribute wood or effective shading. The size and composition of each riparian stand was examined to determine whether trees were large enough to contribute logs that would form pools in the adjacent channel, with pool-forming size of wood a function of channel width. Riparian stands were classified according to whether they passed this pool-forming test. Model results were an exact match to actual conditions in 69% of field-verified stands. A large proportion (74%) of the stands failing the test in reaches of anadromous fish use were in agricultural areas. Passing stands typically had high shade levels, because both stream shade and effective large woody debris size are a function of the size of the trees relative to the size of the stream. The GIS layer of passing and failing riparian stands can be combined with layers depicting property ownership, threatened fish distribution, and other information to objectively prioritize riparian restoration locations and strategies.

Hylander, Kristoffer, Jonsson, Bengt Gunnar, Nilsson, Christer. (2002). Evaluating Buffer Strips along Boreal Streams Using Bryophytes as Indicators, *Ecological Applications*, Vol. 12, No. 3 (Jun., 2002), pp. 797-806, <http://www.jstor.org/stable/3060990>

Buffer strips have recently become the main management practice for reducing logging impact on stream habitats in boreal and temperate regions. The habitat value of buffer strips, however, has not received much attention, although riparian forests belong to the systems with the highest biodiversity in these regions. We used plants as indicators of the ability of buffer strips to maintain an environment similar to intact riparian forests in a boreal forest landscape in northern Sweden. We measured the growth of three common bryophyte species (*Hylocomiastrum umbratum*, *Calypogeia integristipula*, and *Tritomaria quinquedentata*) transplanted to riparian habitat close to a stream in clear-cut logged sites, 10-15 m wide buffer strips on each side of the stream, and intact (reference) sites. Each of the three site categories included six wet and six moist-mesic sites and the experiment was followed over three months in 1999. The species remained vital in the reference sites and grew substantially during the 3-mo-long experiment, but in the logged sites almost no growth was registered, and many shoots died (except for *T. quinquedentata*). The pattern was consistent irrespective of the ground moisture class. The performance of bryophytes in the moist-mesic buffer strips was almost as bad as in the logged sites, whereas in the wet buffer strips it was either intermediate between that in logged and reference sites (*H. umbratum*) or very similar to that in reference sites (*C. integristipula* and *T. quinquedentata*). The edge effect has previously been shown to vary depending on edge orientation, edge physiognomy, and

weather conditions. We found that ground moisture can be of major importance as well. Although many buffer strips function better than no strips, 20-30 m wide strips (with a stream in the middle) through a logged area consist entirely of edge habitat. Increasing the buffer width and avoiding clear-cut logging on both sides of a watercourse would be the first steps to take for improving biodiversity conservation in riparian habitats. Our results also show that bryophytes are good indicators of habitat quality and efficient tools for assessing the ecological function of buffer strips.

Jahir, S. C., Lorenz, A. W., Hering, D., Antons, C., Sundermann, A., Jedicke, E., & Haase, P. (2011). River restoration success: a question of perception. *Ecological Applications*. 2007-2015.

What defines success and failure of river restoration measures is a strongly debated topic in restoration science, but standardized approaches to evaluate either are still not available. The debate is usually centered on measurable parameters, which adhere to scientific objectivity. More subjective aspects, such as landscape aesthetics or recreational value, are usually left out, although they play an important role in the perception and communication of restoration success. In this paper, we show that different perceptions of restoration success exist by analyzing data from 26 river restoration measures in Germany. We addressed both objective parameters, such as hydromorphological changes and changes in fish and benthic invertebrate assemblages, from field investigations, and subjective parameters, such as opinions and perceptions, from water managers via an online survey. With regard to the objective hydromorphological and biotic parameters, our results agree with many studies that have reported improvements in the hydromorphology following restoration; however, there is no similar agreement between results concerning changes in the benthic invertebrate and fish assemblages. The objective results do not correspond to the subjective parameters because self-evaluation of the restoration projects by water managers was overly positive. Indeed, 40% of the respondents admitted that their evaluation was based on gut feeling, and only 45% of the restoration measures were monitored or occasionally checked. This lack of objectively recorded data meant that the water managers were not able to reasonably evaluate restoration success. In contrast, some self-evaluation responses reflected a different perception of the restoration success that was based on landscape aesthetic values or on benefit for the public; others adopted a general "condemned to success" attitude. Based on our data, we argue (1) that goals should be thoughtfully formulated prior to restoration implementation and (2) that it is necessary to monitor river restoration success from different perspectives.

Jansson, R., Backx, H., Boulton, A. J., Dixon, M., Dudgeon, D., Hughes, F. M. R., Tockner, K. (2005). Stating mechanisms and refining criteria for ecologically successful river restoration: a comment on Palmer et al. (2005). *Journal of Applied Ecology*, 42, 218–222.

To encourage more project assessment and reporting of restoration outcomes, Palmer et al. (2005) propose five criteria for assessing the ecological success of river restoration. They also suggest that these criteria should help to clarify which activities should qualify for ecological restoration funding and facilitate consistency about what constitutes an ecologically successful restoration project. We critique the five criteria and agree they all

merit inclusion in an assessment of successful river restoration. However, the practical application of measuring self-sustainability (resilience) following restoration is potentially problematic and an explicit timeframe is needed to evaluate the results of the restoration. A sixth criterion is proposed that encourages specific hypotheses and/or a conceptual model of the ecological mechanisms by which the proposed activities will achieve their target. This would enhance our understanding of the mechanisms at play for successful river restoration, and provide a more powerful deductive framework likely to lead to appropriate practices that can be applied across rivers. To explore the potential practical applicability of these six criteria, we applied them to a recently published example of river restoration to ascertain its ecological success. Synthesis and applications. We agree with the criteria proposed by Palmer et al. (2005), although the problems of measuring resilience and defining a timeline for recovery should be addressed. We suggest strengthening the deductive framework of restoration projects by formulating some sort of conceptual model. This step could involve scientists, and be a useful way of involving science more explicitly in restoration activities. Agreed-upon criteria for successful restoration will greatly facilitate evaluation of river ecosystem recovery at the critical broader scales where our knowledge is still limited.

Januschke, K., Brunzel, S., Haase, P., & Hering, D. (2011). Effects of stream restorations on riparian mesohabitats, vegetation and carabid beetles. *Biodiversity and Conservation*, 20, 3147–3164.

We investigated the effects of hydromorphological restoration measures (mainly the removal of bank fixations) on riparian mesohabitats, vegetation and carabid beetles by comparing 24 restored to nearby non-restored floodplain sections in Germany. Mesohabitats were recorded along ten equally-spaced transects, plant communities and riparian plant and carabid beetle species along three transects per section. Based on 18 indices including habitat and species diversity, taxonomic diversity and functional indices we compared the frequency and magnitude of changes following restoration, both for the overall dataset and for each site individually. Riparian habitat diversity doubled in restored sections compared to non-restored sections. The numbers of vegetation units and plant and carabid beetle species richness also doubled in restored sections, whereas changes in Shannon diversity were most pronounced for mesohabitats and riparian plants. Taxonomic diversity of carabid beetles decreased in restored sections reflecting post restoration dominance of riparian Bembidion species. Stress-tolerant pioneers of plant and especially carabid species benefit strongly from the re-establishment of open sand and gravel bars, while hygrophilous species, which also include non-riparian species, did not respond to restoration. We conclude that restoring river hydromorphology has almost generally positive effects on riparian habitats and riparian biodiversity. Riparian biota are thus well-suited indicators for the effects of hydromorphological restoration. Electronic

Johansson, M. E. and Nilsson, C. (2002). Responses of Riparian Plants to Flooding in Free-Flowing and Regulated Boreal Rivers: An Experimental Study, *Journal of Applied Ecology*, Vol. 39, No. 6 (Dec., 2002), pp. 971-986, <http://www.jstor.org/stable/827284>

The long history of river regulation has resulted in extensively changed ecosystem structures and processes in rivers and their associated environments. This fact, together with changing climatic and hydrological conditions, has increased the need to recover the natural functions of rivers. To develop guidelines for river restoration, comparative ecological experiments at

contrasting water-level regimes are needed. We compared growth and survival of transplanted individuals of four riparian plant species (*Betula pubescens*, *Carex acuta*, *Filipendula ulmaria* and *Leontodon autumnalis*) over 2 years on four free-flowing and four regulated riverbank sites in northern Sweden. The species were chosen as representatives of dominating life-forms and species traits on different elevations of the riverbanks. 2. In *Betula* and *Filipendula*, mean proportional growth rates were significantly higher at free-flowing sites than at regulated sites, whereas no consistent differences between free-flowing and regulated sites were found in *Carex* and *Leontodon*. Differences among species were generally in accordance with natural distribution patterns along riverbank elevation gradients and with experimental evidence on flooding tolerance, although plants of all species survived and even showed positive growth rates on elevations below their natural range of occurrence. 3. Partial least squares regression was used to relate plant performance (growth and survival) to duration, frequency and timing of flooding at the different sites. Flood duration and frequency typically reduced performance in all species and during all time periods, although to various degrees. Flood events early in the experiment determined the outcome to a high degree at all sites. Variables indicating a regulated regime were mostly negatively related to plant performance, whereas free-flowing regime variables were positively related to plant performance. 4. We used two of the regression models generated from our data with an acceptably high predictive power to simulate a hypothetical re-regulation scenario in run-of-river impoundments. With an overall reduction in flooding duration and frequency of 50-75%, plant performance of *Filipendula* at low riverbank elevations showed predicted increases of about 20-30%, levelling off to zero at the highest elevations. Reductions in summer floods represented about one-third to half of this increase. 5. We conclude that for a range of species individual plant performance is clearly reduced on banks of impoundments and storage reservoirs due to changes in the water-level regime. Furthermore, our model simulation suggests that rather substantial reductions of flood duration and frequency are needed to improve plant performance on riverbanks upstream from dams in impounded rivers. River restoration principles should, however, be based on a combination of experimental data on plant performance of individual species and observed long-term changes in plant communities of regulated rivers. Consequently, successful re-regulation schemes in boreal rivers should include both reductions of summer and winter floods as well as re-introduced spring floods.

Jones, K. B., Slonecker, E. T., Nash, M. S., Neale, A. C., Wade, T. G., & Hamann, S. (2010). Riparian habitat changes across the continental United States (1972–2003) and potential implications for sustaining ecosystem services. *Landscape Ecology*. 1261-1275.

Riparian ecosystems are important elements in landscapes that often provide a disproportionately wide range of ecosystem services and conservation benefits. Their protection and restoration have been one of the top environmental management priorities across the US over the last several years. Despite the level of concern, visibility and management effort, little is known about trends in riparian habitats. Moreover, little is known about whether or not cumulative efforts to restore and protect riparian zones and floodplains are affecting the rates of riparian habitat change nationwide. To address these issues, we analyzed riparian land cover change between the early 1970s and the late 1990s/early 2000s using existing spatial data on hydrography and land cover. This included an analysis of land cover changes within 180 m riparian buffer zones, and at catchment

scales, for 42,363 catchments across 63 ecoregions of the continental US. The total amount of forest and natural land cover (forests, shrublands, wetlands) in riparian buffers declined by 0.7 and 0.9%, respectively across the entire study period. Gains in grassland/shrubland accounted for the 0.2% lower percentage of total natural land cover loss relative to forests. Conversely, urban and developed land cover (urban, agriculture, and mechanically disturbed lands) increased by more than 1.3% within riparian buffers across the entire study period. Despite these changes, we documented an opposite trend of increasing proportions of natural and forest land cover in riparian buffers versus the catchment scale. We surmise that this trend might reflect a combination of natural recovery and cumulative efforts to protect riparian ecosystems across the US. However, existing models limit our ability to assess the impacts of these changes on specific ecosystem services. We discuss the implications of changes observed in this study on the sustainability of ecosystem services. We also recommend opportunities for future riparian change assessments.

Kauffman, J. B., Beschta, R. L., Otting, N., & Lytjen, D. (1997). An Ecological Perspective of Riparian and Stream Restoration in the Western United States. *Fisheries*, 22, 12–24.

There is an unprecedented need to preserve and restore aquatic and riparian biological diversity before extinction eliminates the opportunity. Ecological restoration is the reestablishment of processes, functions, and related biological, chemical, and physical linkages between the aquatic and associated riparian ecosystems; it is the repairing of damage caused by human activities. The first and most critical step in ecological restoration is passive restoration, the cessation of those anthropogenic activities that are causing degradation or preventing recovery. Given the capacity of riparian ecosystems to naturally recover, often this is all that is needed to achieve successful restoration. Prior to implementation of active restoration approaches (e.g., instream structures, channel and streambank reconfiguration, and planting programs), a period of time sufficient for natural recovery is recommended. Unfortunately, structural additions and active manipulations are frequently undertaken without halting degrading land use activities or allowing sufficient time for natural recovery to occur. These scenarios represent a misinterpretation of ecosystem needs, can exacerbate the degree of degradation, and can cause further difficulties in restoration. Restoration should be undertaken at the watershed or landscape scale. Riparian and stream ecosystems have largely been degraded by ecosystem wide, off-channel activities and, therefore, cannot be restored by focusing solely on manipulations within the channel. While ecological restoration comes at a high cost, it also is an investment in the natural capital of riparian and aquatic systems and the environmental wealth of the nation.

Kentula, M. E. (1997). Approaches to Prioritizing Sites for Riparian Restoration. *Restoration Ecology*, 5, 69–74.

This study compares the results of Olson and Harris (1997) and Russell et al. (1997) in their work to prioritize sites for riparian restoration in the San Luis Rey River watershed. Olson and Harris defined reaches of the mainstem and evaluated the relative potential for restoration and protection based on cover of natural vegetation, land use, and connectivity. Then they used data on geomorphic conditions, plant species composition, and community structure to prescribe strategies for restoration. Russell et al. used a modeling approach within a geographic information system to combine data on wetness and land use/land cover

to identify areas with potential for protection and restoration. They prioritized the areas based on patch size and proximity to extant riparian habitat. The mainstem and associated floodplain defined by Olson and Harris was more than twice the size of the area defined by Russell et al., because Olson and Harris considered the entire valley floor, whereas Russell et al. used a wetness index to identify saturated zones within the floodplain. For seven of the twelve management units delineated along the mainstem, the two studies agreed on a strategy of restoration or protection. They differed on two. No comparison could be made of the three units for which Olson and Harris used project review, a unique category. Agreement of the results is due to the similarity of criteria used to identify and rank sites for protection and restoration; disagreement is due primarily to the level of resolution of the data. Both approaches have potential for use in watershed-level planning. The predictive power of the two approaches may be maximized when they are used in a complementary fashion.

Klein, L. R., Clayton, S. R., Alldredge, J. R., & Goodwin, P. (2007). Long-Term Monitoring and Evaluation of the Lower Red River Meadow Restoration Project, Idaho, U.S.A. *Restoration Ecology*, 15, 223–239.

Although public and financial support for stream restoration projects is increasing, long-term monitoring and reporting of project successes and failures are limited. We present the initial results of a long-term monitoring program for the Lower Red River Meadow Restoration Project in north-central Idaho, U.S.A. We evaluate a natural channel design's effectiveness in shifting a degraded stream ecosystem onto a path of ecological recovery. Field monitoring and hydrodynamic modeling are used to quantify post-restoration changes in 17 physical and biological performance indicators. Statistical and ecological significance are evaluated within a framework of clear objectives, expected responses (ecological hypotheses), and performance criteria (reference conditions) to assess post-restoration changes away from pre-restoration conditions. Compared to pre-restoration conditions, we observed ecosystem improvements in channel sinuosity, slope, depth, and water surface elevation; quantity, quality, and diversity of in-stream habitat and spawning substrate; and bird population numbers and diversity. Modeling documented the potential for enhanced river-floodplain connectivity. Failure to detect either statistically or ecologically significant change in groundwater depth, stream temperature, native riparian cover, and salmonid density is due to a combination of small sample sizes, high interannual variability, external influences, and the early stages of recovery. Unexpected decreases in native riparian cover led to implementation of adaptive management strategies. Challenges included those common to most project-level monitoring-isolating restoration effects in complex ecosystems, securing long-term funding, and implementing scientifically rigorous experimental designs. Continued monitoring and adaptive management that support the establishment of mature and dense riparian shrub communities are crucial to overall success of the project.

Koljonen, S., Louhi, P., Mäki-Petäys, A., Huusko, A. and Muotka, T. (2012). Quantifying the effects of in-stream habitat structure and discharge on leaf retention: implications for stream restoration, *Freshwater Science*, Vol. 31, No. 4 (December 2012), pp. 1121-1130, <http://www.jstor.org/stable/10.1899/11-173.1>

Input, trapping, and retention of coarse particulate organic matter are among the key determinants of resource availability for consumers in forested headwater streams. Retention efficiency is regulated by the interaction between bed roughness and hydrological characteristics. We examined short-term retention of leaf analogs in artificial flumes, where we manipulated streambed structure and discharge using a factorial design. The substrate structures used are widely applied in stream restoration and represent a gradient of increasing bed complexity: channelized streams, channelized streams + moss, boulder additions, boulders + moss, addition of wood (low-wood and high-wood). We assessed whether, and by how much, the retentive efficiency of a stream is enhanced by various restoration structures and whether the effect of discharge on retention efficiency is similar in channelized and differently restored streams. All restoration structures enhanced leaf retention considerably, and even channelized streams containing mosses were highly retentive. At low discharge, channelized streams lacking mosses retained leaf litter less effectively than did the restored streams, whereas retention differed little among restoration treatments. At high discharge, most restoration structures were much less retentive, and differences in retentiveness between restored and channelized streams became insubstantial, except that streams with abundant wood remained highly retentive at all discharges. Our results suggest that all types of structures added to improve stream retentiveness may enhance leaf retention, and thereby contribute to organic matter dynamics of a stream, but the addition of wood of variable sizes is the best long-term solution to forested stream restoration.

Kondolf, G. M. (1998). Lessons learned from river restoration projects in California. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 8, 39–52.

The planning, design and evaluation of a restoration project should be guided largely by an understanding of past channel changes. 2. A historical analysis can sometimes reveal underlying causes of channel change and document prior habitat conditions, both useful in setting appropriate objectives for restoration. 3. Restoration planning should address the historical causes and patterns of channel degradation that cannot be detected by examining current conditions alone. Moreover, ongoing adjustments in the channel and changes in the catchment must be understood when interpreting channel changes following construction of restoration projects. 4. Changes in channel form (and the independent geomorphological variables of run-off and sediment load from the catchment) can be documented from a variety of sources, including historical maps, boundary lines, aerial photography, bridge and pipeline surveys, gauging records, field evidence and archival sources. Historical riparian vegetation, and use by fish and wildlife, may also be documented from early survey records, photographs and written accounts. 5. Historical analysis should cover an area large enough to capture all events potentially influencing the project reach. The entire catchment upstream should be examined to identify events affecting the flow regime and sediment load, such as deforestation or dam construction. For channels in erodible alluvium, the study should include the channel downstream to the first stable grade control to capture events whose effects may propagate upstream, such as channelization or base lowering. 6. Application of historical channel analysis to the San Luis Rey River in California served as a basis for evaluating the potential for (and hydrological constraints upon) riparian restoration.

Kondolf, G. M., Anderson, S., Lave, R., Pagano, L., Merenlender, A., & Bernhardt, E. S. (2007). Two Decades of River Restoration in California: What Can We Learn? *Restoration Ecology*, 15, 516–523.

As part of the National River Restoration Science Synthesis (NRRSS), we developed a summary database of 4,023 stream restoration projects built in California since 1980, from which we randomly selected 44 records for in-depth interviews with project managers. Despite substantial difficulties in gathering the data, we were able to draw conclusions about current design, implementation, monitoring, and evaluation practices used in California projects and compare them with national trends. Although more than half of the projects for which we conducted interviews were located in watersheds for which a management or assessment plan had been prepared, these plans had a limited impact on site selection. We also found that the state lacks a consistent framework for design, monitoring, and reporting restoration projects, and that although monitoring is far more widespread than the information in the NRRSS summary database would suggest, there are still problems with the type, duration, and reporting of monitoring. The general lack of systematic, objective assessment of completed projects hinders the advance of restoration science.

Kondolf, G. M., & Micheli, E. R. (1995). Evaluating stream restoration projects. *Environmental Management*. Vol. 19, Issue 1:1-15.

River and stream restoration projects are increasingly numerous but rarely subjected to systematic post-project evaluation. Without conducting such evaluation and widely disseminating the results, lessons will not be learned from successes and failures, and the field of river restoration cannot advance. Post-project evaluation must be incorporated into the initial design of each project, with the choice of evaluation technique based directly upon the specific project goals against which performance will be evaluated. We emphasize measurement of geomorphic characteristics, as these constitute the physical framework supporting riparian and aquatic ecosystems. Techniques for evaluating other components are briefly discussed, especially as they relate to geomorphic variables. Where possible, geomorphic, hydrologic, and ecological variables should be measured along the same transects in general, postproject monitoring should continue for at least a decade, with surveys conducted after each flood above a predetermined threshold. Project design should be preceded by a historical study documenting former channel conditions to provide insights into the processes responsible for the present channel condition and to suggest earlier, potentially stable channel configurations as possible design models.

Lake, P. S., Bond, N., & Reich, P. (2007). Linking ecological theory with stream restoration. *Freshwater Biology*, 52, 597–615.

Faced with widespread degradation of riverine ecosystems, stream restoration has greatly increased. Such restoration is rarely planned and executed with inputs from ecological theory. In this paper, we seek to identify principles from ecological theory that have been, or could be, used to guide stream restoration. In attempts to re-establish populations, knowledge of the species' life history, habitat template and spatio-temporal scope is critical. In many cases dispersal will be a critical process in maintaining viable populations at the landscape scale, and special attention should be given to the unique geometry of stream

systems One way by which organisms survive natural disturbances is by the use of refugia, many forms of which may have been lost with degradation. Restoring refugia may therefore be critical to survival of target populations, particularly in facilitating resilience to ongoing anthropogenic disturbance regimes. Restoring connectivity, especially longitudinal connectivity, has been a major restoration goal. In restoring lateral connectivity there has been an increasing awareness of the riparian zone as a critical transition zone between streams and their catchments. Increased knowledge of food web structure - bottom-up versus top-down control, trophic cascades and subsidies - are yet to be applied to stream restoration efforts. In restoration, species are drawn from the regional species pool. Having overcome dispersal and environmental constraints (filters), species persistence may be governed by local internal dynamics, which are referred to as assembly rules. While restoration projects often define goals and endpoints, the succession pathways and mechanisms (e.g. facilitation) by which these may be achieved are rarely considered. This occurs in spite of a large body of general theory on which to draw. Stream restoration has neglected ecosystem processes. The concept that increasing biodiversity increases ecosystem functioning is very relevant to stream restoration. Whether biodiversity affects ecosystem processes, such as decomposition, in streams is equivocal. Considering the spatial scale of restoration projects is critical to success. Success is more likely with large-scale projects, but they will often be infeasible in terms of the available resources and conflicts of interest. Small-scale restoration may remedy specific problems. In general, restoration should occur at the appropriate spatial scale such that restoration is not reversed by the prevailing disturbance regime. The effectiveness and predictability of stream ecosystem restoration will improve with an increased understanding of the processes by which ecosystems develop and are maintained. Ideas from general ecological theory can clearly be better incorporated into stream restoration projects. This will provide a twofold benefit in providing an opportunity both to improve restoration outcomes and to test ecological theory

Landers, D. H. (2008). Riparian Restoration: Current Status and the Reach to the Future. *Restoration Ecology*, 5, 113–121.

Nine Articles in the special issue of Restoration Ecology addressing the subject of site selection for riparian restoration activities were critically examined for this review. The approaches described make significant and original contributions to the field of riparian restoration. All are interdisciplinary to some extent, often combining the fields of hydrology, geomorphology, and biology in the design of restorations. A common component among the articles is that they take a broad view, if not a watershed view, of restoration site selection. The approaches can be generally described as top-down strategic approaches to siting restorations, as opposed to the more methods- and site-driven bottom-up, or tactical, approach. All the articles recognize the importance of developing endpoints related to the ecological function of riparian ecosystems. They succeed in their quest for these indicators of ecological function to varying degrees. The most common indicator used in these papers is riparian vegetation. Several additional elements of scientific investigation, if successfully pursued, could provide vital information and advance our understanding of riparian restoration: developing interdisciplinary approaches more fully; defining endpoints and reference conditions; implementing multiple scale approaches; viewing restorations as experimental ecosystem manipulations; developing a philosophy regarding exotic species; incorporating geographic information systems more often; and integrating science, society,

and politics. The foundation provided by the contributions in this issue should provide a strong basis for the rapid advancement of future research in the area of riparian restoration.

Langendoen, E. J., Lowrance, R. R., & Simon, A. (2009). Assessing the impact of riparian processes on streambank stability. *Ecohydrology*, 2, 360–369.

The series of biennial United States (US) National Water Quality Inventory Surveys shows no reduction in the percentage of degraded miles of streams since the early 1990s despite an exponential increase in river restoration projects to improve water quality, enhance in-stream habitat and manage the riparian zone. This may suggest that many river restoration projects fail to achieve their objectives. This is partly due to a lack of understanding of the dynamics of the degraded riverine system and its interaction with the riparian zone. These projects could, therefore, benefit from using proven models of stream and riparian processes to guide restoration design and to evaluate indicators of ecological integrity. The US Department of Agriculture has developed two such models: the channel evolution computer model CONCEPTS and the riparian ecosystem model REMM. These models have been integrated to evaluate the impact of edge-of-field and riparian conservation measures on stream morphology and water quality. Vegetative riparian conservation measures are commonly used to stabilize failing streambanks. The shear strength of bank soils is, really affected by the degree of saturation of the soils and root reinforcement provided by riparian vegetation. The integrated model was used to study the effectiveness of woody and herbaceous riparian buffers in controlling streambank erosion of an incised stream in northern Mississippi. Comparison of model results with observations showed that pore-water pressures are accurately predicted in the upper part of the streambank, away from the groundwater table. Simulated pore-water pressures deviate from those observed lower in the streambank near the phreatic surface. These discrepancies are mainly caused by differences in the simulated location of the phreatic surface and simulated evapotranspiration in case of the woody buffer. The modelling exercise further showed that a coarse rooting system, e.g. as provided by trees, significantly reduced bank erosion rates for this deeply incised stream. Published in 2009 by John Wiley & Sons, Ltd.

Laub, B. G., Palmer, M. A., & Gene E Likens. (2009). Restoration Ecology of Rivers. *Encyclopedia of Inland Waters* (pp. 332–341).

Worldwide, people are becoming aware of the degraded condition of many rivers, and they are increasingly turning to river restoration to help river systems return to a more natural state. As a result, restoration ecology is becoming an important science in the management of the rivers worldwide. In this article, we discuss the present state of restoration ecology. We begin with a synopsis of some common causes of river degradation and the motivation for attempting river restoration. We then discuss the ideal goals for ecological restoration of rivers and how this process is necessarily constrained in human-dominated systems. River restoration in human-dominated systems is presented as a three-step process: planning, implementation, and monitoring. We conclude with an overview of future challenges for restoration ecology and some possible innovations to help address those challenges.

Lehmkuhl, John F., Dorsey Burger, E., Drew, Emily K. , Lindsey, John P., Haggard, Maryellen and Woodruff, Kent Z. (2007). Breeding Birds in Riparian and Upland Dry Forests of the

We quantified breeding bird abundance, diversity, and indicator species in riparian and upland dry forests along 6 third- to fourth-order streams on the east slope of the Cascade Range, Washington, USA. Upland dry forest on southerly aspects was dominated by open ponderosa pine (*Pinus ponderosa*) and dry Douglas-fir (*Pseudotsuga menziesii*) plant associations. Upland mesic forest on northerly aspects was dominated by closed-canopy Douglas-fir or dry grand fir (*Abies grandis*) plant associations. Riparian overstory vegetation was dominated by black cottonwood (*Populus trichocarpa*) plant associations with a prominent hardwood tree and shrub component. We quantified bird assemblages, diversity, and abundance from parallel point transects on riparian and adjacent dry and mesic upslope forests. We detected 80 bird species from >12,000 point-transect observations during 1998-1999. Eighteen species accounted for 75% of all detections. Species richness and evenness were similar in all 3 forest types, with approximately 35 species and high evenness (0.85) in each forest type. Bird species assemblages differed among dry, mesic, and riparian forest types, with the greatest differences between riparian and both dry and mesic upland forests. Riparian forest had the greatest number (9) of strong characteristic, or indicator, species among the 3 forest types. Upland mesic forest was characterized by 7 indicator species. Upland dry forest had 4 indicator species. Our results indicate that current standards and guidelines for riparian buffers zones would allow for avian refuge and corridor functions along these streams. Forest managers could use our indicator species to predict and monitor shifts in upland forest species composition from thinning and prescribed burning practices that are used to reduce fuels in uplands and to reduce continuity of fire effects between riparian and upland zones.

Lennox, M. S., Lewis, D. J., Jackson, R. D., Harper, J., Larson, S., & Tate, K. W. (2011). Development of Vegetation and Aquatic Habitat in Restored Riparian Sites of California's North Coast Rangelands. *Restoration Ecology*, 19, 225-233.

The preponderance of short-term objectives and lack of systematic monitoring of restoration projects limits opportunities to learn from past experience and improve future restoration efforts. We conducted a retrospective, cross-sectional survey of 89 riparian revegetation sites and 13 nonrestored sites. We evaluated 36 restoration metrics at each site and used project age (0-201339 years) to quantify plant community and aquatic habitat trajectories with a maximum likelihood model selection approach to compare linear and polynomial relationships. We found significant correlations with project age for 16 of 21 riparian vegetation, and 11 of 15 aquatic habitat attributes. Our results indicated improvements in multiple ecosystem services and watershed functions such as diversity, sedimentation, carbon sequestration, and available habitat. Ten riparian vegetation metrics, including native tree and exotic shrub density, increased nonlinearly with project age, while litter and native shrub density increased linearly. Species richness and cover of annual plants declined over time. Improvements in aquatic habitat metrics, such as increasing pool depth and decreasing bankfull width-to-depth ratio, indicated potentially improved anadromous fish habitats at restored sites. We hypothesize that certain instream metrics did not improve because of spatial and/or temporal limitations of riparian vegetation to affect aquatic habitat. Restoration managers should be prepared to maintain or enhance understory diversity by

controlling exotic shrubs or planting shade-tolerant native species as much as 10 years after revegetation.

Li, Ming-Han and Eddleman, Karen E. (2002). Biotechnical engineering as an alternative to traditional engineering methods: A biotechnical streambank stabilization design approach, *Landscape and Urban Planning*, Vol. 60, issue 4, Aug. 30, 2002, 225-242.

Focus on ecologically fragile streams in the US has resulted in heightened recognition and popularity of biotechnical streambank stabilization methods. This ancient technique re-emerges in the US in response to the link between traditional protection measures and numerous occurrences of streambank failures. The purpose of this study was to investigate biotechnical engineering as a viable alternative to traditional channelization and hard-armoring methods. Primarily by literature review, this study analyzed and organized various streambank stabilization approaches in traditional engineering, fluvial geomorphological, ecological and biotechnical engineering perspectives. Strengths and weaknesses in these four perspectives are discussed, suitable biotechnical alternatives are presented, and a cost-strength matrix of biotechnical techniques is introduced.

Louhi, Pauliina, Mykrä, Heikki, Paavola, Riku, Huusko, Ari, Vehanen, Teppo, Mäki-Petäys, Aki and Muotka, Timo. Twenty years of stream restoration in Finland: little response by benthic macroinvertebrate communities, *Ecological Applications*, Vol. 21, No. 6 (September 2011), 1950-1961, <http://www.jstor.org/stable/41416630>

The primary focus of many in-stream restoration projects is to enhance habitat diversity for salmonid fishes, yet the lack of properly designed monitoring studies, particularly ones with pre-restoration data, limits any attempts to assess whether restoration has succeeded in improving salmonid habitat. Even less is known about the impacts of fisheries-related restoration on other, non-target biota. We examined how restoration aiming at the enhancement of juvenile brown trout (*Salmo trutta* L.) affects benthic macroinvertebrates, using two separate data sets: (1) a before—after-control-impact (BACI) design with three years before and three after restoration in differently restored and control reaches of six streams; and (2) a space-time substitution design including channelized, restored, and near natural streams with an almost 20-year perspective on the recovery of invertebrate communities. In the BACI design, total macroinvertebrate density differed significantly from before to after restoration. Following restoration, densities decreased in all treatments, but less so in the controls than in restored sections. Taxonomic richness also decreased from before to after restoration, but this happened similarly in all treatments. In the long-term comparative study, macroinvertebrate species richness showed no difference, between the channel types. Community composition differed significantly between the restored and natural streams, but not between restored and channelized streams. Overall, the in-stream restoration measures used increased stream habitat diversity but did not enhance benthic biodiversity. While many macroinvertebrates may be dispersal limited, our study sites should not have been too distant to reach within almost two decades. A key explanation for the weak responses by macroinvertebrate communities may have been historical. When Fennoscandian streams were channelized for log floating, the loss of habitat heterogeneity was only partial. Therefore, habitat may not have been limiting the macroinvertebrate communities to begin with. Stream restoration to support trout fisheries has strong public

acceptance in Finland and will likely continue to increase in the near future. Therefore, more effort should be placed on assessing restoration success from a biodiversity perspective using multiple organism groups in both stream and riparian ecosystems.

Lorena, Armin W., Korte, Thomas, Sundermann, Andrea, Januschke, Kathrin and Haase, Peter. (2012). Macrophytes respond to reach-scale river restorations, *Journal of Applied Ecology*, Vol. 49, No. , 202-21: <http://www.jstor.org/stable/41433340>

In recent years, river restoration science has been searching for biological indicators of improvement in the physical habitats of streams. To date, research has mainly focused on the use of fish and macroinvertebrates as indicators. Despite their importance in aquatic ecosystems, the response of macrophytes to habitat restoration has been rarely studied. We investigated the macrophyte communities of 40 restored river reaches in the lowland and lower mountainous areas of Germany. Each restored reach was compared to an upstream, unrestored reach using a space-for-time-substitution approach. At each reach, a 100 m stretch was surveyed for submerged and emergent macrophytes, recording the quantity, abundance and growth form of each species. Additionally, microhabitat patterns (substrate, depth, current velocity) and channel parameters (mean and bankful width, number of channel elements) were recorded. Restored reaches had a significantly higher macrophyte cover, richness, diversity and number of growth forms. Macrophyte diversity and richness were both positively correlated with depth, current and substrate. The analysis of growth forms showed that Lemnids, Helodids, Parvopotamids, Elodids, Peplids and Juncids are all significant indicators of restoration. These species all responded directly to the restoration measures either by highly increasing in abundance or by being present in the restored reaches and absent in the unrestored reaches. While the restored reaches of the lowland rivers were characterized by a high abundance of Peplids and Parvopotamids, the restored reaches of the mountain rivers showed a significantly higher presence and abundance of Lemnids and Helodids. Three macrophyte species (*Lemna minor*, *Persicaria hydropiper*, *Potamogeton crispus*) were regarded as significant indicators of restoration. No species were found to be indicators of unrestored reaches. Synthesis and applications. Macrophyte communities benefit from river restoration by showing increased cover, abundance and diversity. The main drivers of this enhancement are more natural and diverse substrates and an increased floodplain area in the restored reaches, as well as a greater variability of current and depth patterns. Monitoring of macrophytes could thus be an easy and cost-effective means to gauge the success of river restoration measures.

Marshall, K. N., Hobbs, N. T., & Cooper, D. J. (2013). Stream hydrology limits recovery of riparian ecosystems after wolf reintroduction. *Proceedings of The Royal Society Biological Sciences*, 280.

Efforts to restore ecosystems often focus on reintroducing apex predators to re-establish coevolved relationships among predators, herbivores and plants. The preponderance of evidence for indirect effects of predators on terrestrial plant communities comes from ecosystems where predators have been removed. Far less is known about the consequences of their restoration. The effects of removal and restoration are unlikely to be symmetrical because removing predators can create feedbacks that reinforce the effects of predator loss. Observational studies have suggested that the reintroduction of wolves to Yellowstone

National Park initiated dramatic restoration of riparian ecosystems by releasing willows from excessive browsing by elk. Here, we present results from a decade-long experiment in Yellowstone showing that moderating browsing alone was not sufficient to restore riparian zones along small streams. Instead, restoration of willow communities depended on removing browsing and restoring hydrological conditions that prevailed before the removal of wolves. The 70-year absence of predators from the ecosystem changed the disturbance regime in a way that was not reversed by predator reintroduction. We conclude that predator restoration may not quickly repair effects of predator removal in ecosystems.

McClain, C., Holl, K., & Wood, D. (2011). Successional models as guides for restoration of riparian forest understory. *Restoration Ecology*, 19, 280–289.

We compare two successional models as guides for restoring native riparian understory species along a 160-km stretch of the Sacramento River in California. In 2001 and 2007, we surveyed cover, frequency, and richness of native and exotic understory species in 15 sites planted (1989-1996) with overstory species to determine whether native understory species colonized naturally (passive relay floristics model). In 2007, we surveyed 20 additional sites (planted 1997-2003) in 14 of which understory species were planted (initial floristics model) to evaluate whether planting accelerated community recovery. We surveyed 10 remnant forests as references for successional trajectories. Mean cover and frequency of natives changed little over time in sites where they were not planted initially; increases in native cover in a few sites were primarily due to a single common species (*Galium aparine*). Species composition shifted from light-demanding to shade-adapted species, both exotic and native, in response to a doubling of overstory cover. Sites with high intensity understory plantings had greater cover and frequency of native understory species than unplanted sites, but were still low relative to reference forests. Light-demanding natives (e.g., *Artemisia douglasiana*, *Rubus ursinus*, and grasses) established in sites where they were planted; however, a shade-adapted species (*Carex barbarae*) did not survive well. Our research indicates that the passive relay floristics and the initial floristic composition approaches serve to restore a few common native understory species, but that planting species as site conditions become appropriate (active relay floristics model) will be needed to restore entire native understory communities.

Meyer and Baer, W. (2010). Plant Community Recovery following Restoration in Temporally Variable Riparian Wetlands. *Restoration Ecology*. Volume 52–64.

Wetlands historically provided many ecosystem services but most have been lost or degraded through land conversion. Recent appreciation for wetland values and increasing ecotourism in the Central Platte River Valley (U.S.A.) has promoted restoration of wet meadow systems, although recovery patterns are not well known. We quantified plant community structure in sloughs (deeper habitats) and adjacent margins (slightly higher elevation) of six wetland sites, restored for 1-7 years at the onset of a 3-year study, and three natural wetlands to assess recovery dynamics. Plant community metrics recovered differentially between habitats. Within restored margins, richness and diversity showed a weak quadratic response with time since restoration, indicating that both indexes overshoot natural levels shortly following restoration. Within sloughs, richness and diversity showed no change with time, suggesting that recovery occurs more quickly in these deeper, moister

habitats. Percent similarity of plant communities in restorations and natural wetlands increased linearly over time. However, ordinations of plant community composition showed that recovery was strongly influenced by site-specific hydrology and that recovery may not be a linear trajectory toward natural systems. The analysis and interpretation of plant community dynamics revealed several challenges to restoration assessment, including the role of interannual variability in precipitation, limitations to hydrologic recovery, and temporal variability in plant community structure in natural systems that resulted in "moving targets" for recovery comparisons. Temporal variability in climate must be considered when assessing restoration success in systems where plant community structure is responsive to variable moisture regimes.

Moggridge, Helen L., Gurnell, Angela M. and Mountford, J. Owen. (2009). Propagule Input, Transport and Deposition in Riparian Environments: The Importance of Connectivity for Diversity, *Journal of Vegetation Science*, Vol. 20, No. 3, 465-474, <http://www.jstor.org/stable/25549271>

Question: How important is hydrochory for dispersing propagules along riverbanks and to what extent do the quantity and species composition of deposited propagules reflect the riparian vegetation, represent "new" species that are not present in the vegetation, and vary with river flow and season? Location: River Frome, Dorset, UK. Methods: Over 13 consecutive 6-week time periods, during which river water levels were continuously monitored, aerial inputs of propagules to riverbanks were sampled using funnels, hydrochorous propagule transport was sampled using drift nets, and deposition across the riverbanks was sampled using astroturf mats. A survey of the riparian vegetation enabled comparison between samples and the standing vegetation, so that "new" species could be identified. Differences in propagule abundance and diversity between sampling methods, time periods and locations were tested using Mann-Whitney U-tests and Kruskal-Wallis ANOVA. DCA established contrasts in the floristic composition of all deposited propagules and "new" propagules between different sample types, time periods and locations. Results: Aerial seed fall generated few propagules of low species richness. Hydrochory introduced large numbers of propagules and new species, resulting in high propagule deposition on the riverbank. The number and diversity of deposited propagules was governed by seasonal patterns of seed release and the hydrological regime. Propagule deposition was significantly greater on the most frequently inundated parts of the riverbank and autumn floods were particularly important for transporting "new" species to the study site and for remobilizing previously released propagules. Conclusions: The abundance and diversity of propagules deposited along riverbanks is dependent upon high river flows, which facilitates connectivity between the channel and the riparian zone.

Moore, Dan R., and Richardson, John S. (2012). Natural disturbance and forest management in riparian zones: comparison of effects at reach, catchment, and landscape scales, *Freshwater Science*, 31 (1), 239-247.

Forest disturbance agents, such as wildfire and wind throw, often differ in magnitude and frequency between upland and riparian zones. Riparian forests may be subject to additional disturbance agents that do not affect uplands, including debris flows, floods, bank erosion, and avulsions. Forest harvesting, with or without a streamside buffer, is an additional

riparian disturbance agent in managed landscapes. The effects of riparian harvesting on stream habitat and ecology are qualitatively similar to those of wildfire, with the important exception of recruitment of large in-stream wood. For most other disturbance agents, current knowledge is insufficient to assess the degree to which natural disturbance can be emulated via riparian forest harvesting. In particular, the effects of the spatial patterns and frequencies of disturbance on the trajectories and rates of post disturbance recovery are poorly understood for many landscapes and are complicated by the potential for propagation of effects down the stream network. Broadly based, long-term research on riparian disturbance regimes is needed to provide the scientific basis required for designing strategies for sustainable streamside forest management.

Naiman, R. J., Alldredge, J. R., Beauchamp, D., Bisson, P., Congleton, J., Henny, C. J., Wood, C. C. (2012). Developing a broader scientific foundation for river restoration: Columbia River food webs. *Proceedings of the National Academy of Sciences of the United States of America*, 109, 21201–7.

Well-functioning food webs are fundamental for sustaining rivers as ecosystems and maintaining associated aquatic and terrestrial communities. The current emphasis on restoring habitat structure--without explicitly considering food webs--has been less successful than hoped in terms of enhancing the status of targeted species and often overlooks important constraints on ecologically effective restoration. We identify three priority food web-related issues that potentially impede successful river restoration: uncertainty about habitat carrying capacity, proliferation of chemicals and contaminants, and emergence of hybrid food webs containing a mixture of native and invasive species. Additionally, there is the need to place these food web considerations in a broad temporal and spatial framework by understanding the consequences of altered nutrient, organic matter (energy), water, and thermal sources and flows, reconnecting critical habitats and their food webs, and restoring for changing environments. As an illustration, we discuss how the Columbia River Basin, site of one of the largest aquatic/riparian restoration programs in the United States, would benefit from implementing a food web perspective. A food web perspective for the Columbia River would complement ongoing approaches and enhance the ability to meet the vision and legal obligations of the US Endangered Species Act, the Northwest Power Act (Fish and Wildlife Program), and federal treaties with Northwest Indian Tribes while meeting fundamental needs for improved river management.

Naiman, R. J., Decamps, H., & Pollock, M. (1993). The Role of Riparian Corridors in Maintaining Regional Biodiversity. *Ecological Applications*, 3, 209–212.

Riparian corridors possess an unusually diverse array of species and environmental processes. This ecological diversity is related to variable flood regimes, geomorphic channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. This dynamic environment results in a variety of life history strategies, and a diversity of biogeochemical cycles and rates, as organisms adapt to disturbance regimes over broad spatio-temporal scales. These facts suggest that effective riparian management could ameliorate many ecological issues related to land use and environmental quality. We contend that riparian corridors should play an essential role in water and landscape planning, in the

restoration of aquatic systems, and in catalyzing institutional and societal cooperation for these efforts.

Naiman, Robert J.; Decamps, Henri (1997). The Ecology of Interfaces: Riparian Zones, *Annual Review of Ecology and Systematics*, Vol. 28, 621-658, <http://www.jstor.org/stable/2952507>

Riparian zones possess an unusually diverse array of species and environmental processes. The ecological diversity is related to variable flood regimes, geographically unique channel processes, altitudinal climate shifts, and upland influences on the fluvial corridor. The resulting dynamic environment supports a variety of life-history strategies, biogeochemical cycles and rates, and organisms adapted to disturbance regimes over broad spatial and temporal scales. Innovations in riparian zone management have been effective in ameliorating many ecological issues related to land use and environmental quality. Riparian zones play essential roles in water and landscape planning, in restoration of aquatic systems, and in catalyzing institutional and societal cooperation for these efforts.

Nilsson, Christer, Jansson, Roland, Kuglerová, Lenka, Lind, Lovisa and Ström, Lotta, Boreal. (2013) Riparian Vegetation Under Climate Change, *Ecosystems*, Vol. 16, No. 3, 401-410, <http://www.jstor.org/stable/23501467>

Climate-change models predict that in most parts of the boreal region these zones will be affected by various combinations of increased temperature, less seasonal variation in runoff, increased average discharge, changes in groundwater supply, and a more dynamic ice regime. Increasing temperatures will favor invasion of exotic species whereas species losses are likely to be minor. The hydrologic changes will cause a narrowing of the riparian zone and, therefore, locally reduce species richness whereas effects on primary production are more difficult to predict. More shifts between freezing and thawing during winter will lead to increased dynamics of ice formation and ice disturbance, potentially fostering a more dynamic and species-rich riparian vegetation. Restoration measures that increase water retention and shade, and that reduce habitats for exotic plant species adjacent to rivers can be applied especially in streams and rivers that have been channelized or deprived of their riparian forest to reduce the effects of climate change on riparian ecosystems.

Nilsson, C., & Svedmark, M. (2002). Basic principles and ecological consequences of changing water regimes: riparian plant communities. *Environmental Management*, 30, 468–480.

Recent research has emphasized the importance of riparian ecosystems as centers of biodiversity and links between terrestrial and aquatic systems. Riparian ecosystems also belong among the environments that are most disturbed by humans and are in need of restoration to maintain biodiversity and ecological integrity. To facilitate the completion of this task, researchers have an important function to communicate their knowledge to policy-makers and managers. This article presents some fundamental qualities of riparian systems, articulated as three basic principles. The basic principles proposed are: (1) The flow regime determines the successional evolution of riparian plant communities and ecological processes. (2) The riparian corridor serves as a pathway for redistribution of organic and inorganic material that influences plant communities along rivers. (3) The riparian system is a transition zone between land and water ecosystems and is disproportionately plant species-

rich when compared to surrounding ecosystems. Translating these principles into management directives requires more information about how much water a river needs and when and how, i.e., flow variables described by magnitude, frequency, timing, duration, and rate of change. It also requires information about how various groups of organisms are affected by habitat fragmentation, especially in terms of their dispersal. Finally, it requires information about how effects of hydrologic alterations vary between different types of riparian systems and with the location within the watershed.

Opperman, J. J., and Merenlender, A. M. (2000). Deer herbivory as an ecological constraint to restoration of degraded riparian corridors. *Restoration Ecology*, 8, 41–47.

Ungulate herbivory can impact riparian vegetation in several ways, such as by reducing vigor or reproductive output of mature plants, and through increased mortality of seedlings and saplings. Much work has focused on the effects of livestock grazing within riparian corridors, while few studies have addressed the influence of native ungulate herbivory on riparian vegetation. This study investigated the effect of deer herbivory on riparian regeneration along three streams with degraded riparian corridors in Mendocino County, California. We utilized existing stream restoration efforts by private landowners and natural resource agencies to compare six deer exclosures with six upstream control plots. Livestock were excluded from both exclosure and control plots. Three of the deer exclosures had been in place for 15 years, one for 6 years, and two for 4 years. The abundance and size distribution of woody riparian plant species such as *Salix exigua*, *S. laevigata*, *S. lasiolepis*, *Alnus rhombifolia*, and *Fraxinus latifolia* were quantified for each exclosure and control plot. The mean density of saplings in deer exclosures was $0.49 \pm 0.15/\text{m}^2$, while the mean density of saplings in control plots was $0.05 \pm 0.02/\text{m}^2$. Within exclosures, 35% of saplings were less than 1 m and 65% were greater than 1 m; within control plots, 97% of saplings were less than 1 m in height. The fact that little regeneration had occurred in control plots suggests that deer herbivory can substantially reduce the rate of recovery of woody riparian species within degraded riparian corridors. Exclusionary fencing has demonstrated promising results for riparian restoration in a region with intense deer herbivory

Paetzold, A., Yoshimura, C., & Tockner, K. (2008). Riparian arthropod responses to flow regulation and river channelization. *Journal of Applied Ecology*, 45, 894–903.

Alterations to river flow and morphology widely impact riverine habitats. Little is known about the consequences of such alterations on riparian arthropods, although they contribute substantially to riverine biodiversity and play a critical role in linking aquatic and terrestrial food webs. We investigated the interactive effects of flow regulation (hydropeaking) and river channelization on gravel-bar habitat characteristics and riparian arthropods in seven Alpine rivers. Digital elevation models were developed to simulate inundation dynamics of each gravel bar. Channelization significantly increased inundation frequency, and hydropeaking increased substrate embeddedness. The total abundance of riparian arthropods was significantly reduced by hydropeaking, whereas arthropod species richness was reduced by both hydropeaking and channelization. Sites that were affected by both hydrological and morphological modifications together were almost devoid of arthropods. The sensitivity of riparian arthropods to alterations in flow and morphology differed among taxa. Spider abundance and richness were significantly reduced by channelization only. Ground beetles

showed no significant response. Rove beetle abundance and richness were negatively affected by hydropeaking whereas channelization had a negative effect only in rivers with hydropeaking. Abundance and richness of all taxa combined, and of spiders independently, were negatively correlated with inundation frequency and substrate embeddedness. Rove beetle abundance and richness were negatively correlated with embeddedness. Spider and rove beetle richness were also correlated with gravel bar area. Synthesis and applications. Our results indicate that the richness and abundance of riparian arthropods were predominantly affected by the availability of exposed gravel above the average high-water level and substrate embeddedness. Restoration of riverbank morphology and mitigation of hydropeaking are likely to benefit riparian arthropods. Riparian arthropods, particularly spiders and rove beetles, appear to be sensitive indicators of the ecological effects of hydromorphological alterations in rivers

Paillex, A., Dolédec, S., Castella, E., & Méricoux, S. (2009). Large river floodplain restoration: predicting species richness and trait responses to the restoration of hydrological connectivity. *Journal of Applied Ecology*. Volume 46, Issue 1, pages 250–258.

Floodplains are species-rich environments often strongly impacted by human activities. In particular, the negative effects of progressive and rapid disconnection of secondary channels have led to restoration programmes and a growing interest in restoration ecology. Current restoration strategies in large river floodplains focus on the macroinvertebrate response related to the increases in lateral connectivity of the secondary channels. We constructed a framework to assess a gradient of hydrological connectivity among 13 secondary channels and the main channel of a large river, and we modelled the response of a set of macroinvertebrate metrics to this gradient. Comparisons between predicted and observed metrics in restored channels allowed us to measure the effect of an increase in the hydrological connectivity on the biological characteristics of macroinvertebrate assemblages. The pre-restoration framework enabled a clear ordering of channels into three types according to levels of hydrological connectivity. Rarefied richness and species traits, responding to the connectivity gradient, showed a net difference between disconnected channels and the main river channel. We were able to highlight a predation–colonization trade-off along the gradient of hydrological connectivity with a maximum colonization potential in the most connected channels. Post-restoration sampling showed deviations of the restored channels from their expected ecological state. A large proportion of colonizers were favoured by the restoration operations and non-native species occurred in the restored channels. Synthesis and applications. Macroinvertebrate biodiversity in large river floodplains is shaped by lateral hydrological connectivity. Increasing hydrological connectivity led to an increase in colonization rate. One year after restoration, the increase in lateral connectivity had shifted the restored sites away from the predicted state. This unpredictability is, in part, a consequence of the rapid colonization by non-native species of new habitats created by the restoration measures. We recommend that floodplain-scale restoration should focus on diversification of the hydrological connectivity of channels, thereby conserving a maximum of functional characteristics in macroinvertebrate communities.

Palmer, M. A., Allan, J. D., Lake, P. S., Brooks, S., Carr, J., Clayton, S., Sudduth, E. (2005). Standards for ecologically successful river restoration. *Journal of Applied Ecology*, 42, 208–217.

Increasingly, river managers are turning from hard engineering solutions to ecologically based restoration activities in order to improve degraded waterways. River restoration projects aim to maintain or increase ecosystem goods and services while protecting downstream and coastal ecosystems. There is growing interest in applying river restoration techniques to solve environmental problems, yet little agreement exists on what constitutes a successful river restoration effort. We propose five criteria for measuring success, with emphasis on an ecological perspective. First, the design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Secondly, the river's ecological condition must be measurably improved. Thirdly, the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed. Fourthly, during the construction phase, no lasting harm should be inflicted on the ecosystem. Fifthly, both pre- and post-assessment must be completed and data made publicly available. Determining if these five criteria have been met for a particular project requires development of an assessment protocol. We suggest standards of evaluation for each of the five criteria and provide examples of suitable indicators. Synthesis and applications. Billions of dollars are currently spent restoring streams and rivers, yet to date there are no agreed upon standards for what constitutes ecologically beneficial stream and river restoration. We propose five criteria that must be met for a river restoration project to be considered ecologically successful. It is critical that the broad restoration community, including funding agencies, practitioners and citizen restoration groups, adopt criteria for defining and assessing ecological success in restoration. Standards are needed because progress in the science and practice of river restoration has been hampered by the lack of agreed upon criteria for judging ecological success. Without well-accepted criteria that are ultimately supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes. Improving methods and weighing the ecological benefits of various restoration approaches require organized national-level reporting systems. *Journal of Applied Ecology* (2005).

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

Despite some highly visible projects that have resulted in environmental benefits, recent efforts to quantify the number and distribution of river restoration projects revealed a paucity of written records documenting restoration outcomes. Improving restoration designs and setting watershed priorities rely on collecting and making accessible this critical information. Information within the unpublished notes of restoration project managers is useful but rarely documents ecological improvements. This special section of *Restoration Ecology* is devoted to the current state of knowledge on river restoration. We provide an overview of the section's articles, reflecting on lessons learned, which have implications for the implementation, legal, and financing frameworks for restoration. Our reflections are informed by two databases developed under the auspices of the National River Restoration

Science Synthesis project and by extensive interactions with those who fund, implement, and permit restoration. Requiring measurable ecological success criteria, comprehensive watershed plans, and tracking of when and where restoration projects are implemented are critical to improving the health of U.S. waters. Documenting that a project was put in the ground and stayed intact cannot be equated with ecological improvements. However, because significant ecological improvements can come with well-designed and -implemented stream and river restorations, a small investment in documenting the factors contributing to success will lead to very large returns in the health of our nation's waterways. Even projects that may appear to be failures initially can be turned into success stories by applying the knowledge gained from monitoring the project in an adaptive restoration approach.

M. A. Palmer, E. S. Bernhardt, J. D. Allan, P. S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. N. Dahm, J. Follstad Shah, D. L. Galat, S. G. Loss, P. Goodwin, D. D. Hart, B. Hassett, R. Jenkinson, G. M. Kondolf, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano and E. Sudduth. (2005). Standards for Ecologically Successful River Restoration. (2005). *Journal of Applied Ecology*, 42, (2), 208-217, <http://www.jstor.org/stable/3505713>

Increasingly, river managers are turning from hard engineering solutions to ecologically based restoration activities in order to improve degraded waterways. River restoration projects aim to maintain or increase ecosystem goods and services while protecting downstream and coastal ecosystems. There is growing interest in applying river restoration techniques to solve environmental problems, yet little agreement exists on what constitutes a successful river restoration effort. 2. We propose five criteria for measuring success, with emphasis on an ecological perspective. First, the design of an ecological river restoration project should be based on a specified guiding image of a more dynamic, healthy river that could exist at the site. Secondly, the river's ecological condition must be measurably improved. Thirdly, the river system must be more self-sustaining and resilient to external perturbations so that only minimal follow-up maintenance is needed. Fourthly, during the construction phase, no lasting harm should be inflicted on the ecosystem. Fifthly, both pre- and post-assessment must be completed and data made publicly available. 3. Determining if these five criteria have been met for a particular project requires development of an assessment protocol. We suggest standards of evaluation for each of the five criteria and provide examples of suitable indicators. 4. Synthesis and applications. Billions of dollars are currently spent restoring streams and rivers, yet to date there are no agreed upon standards for what constitutes ecologically beneficial stream and river restoration. We propose five criteria that must be met for a river restoration project to be considered ecologically successful. It is critical that the broad restoration community, including funding agencies, practitioners and citizen restoration groups, adopt criteria for defining and assessing ecological success in restoration. Standards are needed because progress in the science and practice of river restoration has been hampered by the lack of agreed upon criteria for judging ecological success. Without well-accepted criteria that are ultimately supported by funding and implementing agencies, there is little incentive for practitioners to assess and report restoration outcomes. Improving methods and weighing the ecological benefits of various restoration approaches require organized national-level reporting systems.

Palmer, M. A., Menninger, H. L., & Bernhardt, E. (2010). River restoration, habitat heterogeneity and biodiversity: a failure of theory or practice? *Freshwater Biology*, 55, 205–222.

Stream ecosystems are increasingly impacted by multiple stressors that lead to a loss of sensitive species and an overall reduction in diversity. A dominant paradigm in ecological restoration is that increasing habitat heterogeneity (HH) promotes restoration of biodiversity. This paradigm is reflected in stream restoration projects through the common practice of re-configuring channels to add meanders and adding physical structures such as boulders and artificial riffles to restore biodiversity by enhancing structural heterogeneity. To evaluate the validity of this paradigm, we completed an extensive evaluation of published studies that have quantitatively examined the reach-scale response of invertebrate species richness to restoration actions that increased channel complexity. We also evaluated studies that used manipulative or correlative approaches to test for a relationship between physical heterogeneity and invertebrate diversity in streams that were not in need of restoration. We found habitat and macro-invertebrate data for 78 independent stream or river restoration projects described by 18 different author groups in which invertebrate taxa richness data in response to the restoration treatment were available. Most projects were successful in enhancing physical HH; however, only two showed statistically significant increases in biodiversity rendering them more similar to reference reaches or sites. Studies manipulating structural complexity in otherwise healthy streams were generally small in scale and less than half showed a significant positive relationship with invertebrate diversity. Only one-third of the studies that attempted to correlate biodiversity to existing levels of in-stream heterogeneity found a positive relationship. Across all the studies we evaluated, there is no evidence that HH was the primary factor controlling stream invertebrate diversity, particularly in a restoration context. The findings indicate that physical heterogeneity should not be the driving force in selecting restoration approaches for most degraded waterways. Evidence suggests that much more must be done to restore streams impacted by multiple stressors than simply re-configuring channels and enhancing structural complexity with meanders, boulders, wood, or other structures. Thematic implications: as integrators of all activities on the land, streams are sensitive to a host of stressors including impacts from urbanisation, agriculture, deforestation, invasive species, flow regulation, water extractions and mining. The impacts of these individually or in combination typically lead to a decrease in biodiversity because of reduced water quality, biologically unsuitable flow regimes, dispersal barriers, altered inputs of organic matter or sunlight, degraded habitat, etc. Despite the complexity of these stressors, a large number of stream restoration projects focus primarily on physical channel characteristics. We show that this is not a wise investment if ecological recovery is the goal. Managers should critically diagnose the stressors impacting an impaired stream and invest resources first in repairing those problems most likely to limit restoration.

Parkyn, S. M., Davies-Colley, R. J., Cooper, A. B., & Stroud, M. J. (2005). Predictions of stream nutrient and sediment yield changes following restoration of forested riparian buffers. *Ecological Engineering* 24, 551–558).

Riparian tree planting is widely recognised as a means to improve water quality and stream habitat. However, shading of riparian pasture grasses can lead to channel widening, and riparian shade may limit the growth of macrophytes and algae that assimilate dissolved

nutrients from the water column. We investigated concerns that riparian management could lead to increased yields of nutrients and sediments through a conceptual modelling exercise. A simple model of the trade-off between interception of nutrients in runoff by forest buffers versus reduction of in-stream uptake due to shade, predicted that a buffer strip alongside a small headwater stream would reduce nutrient export, while a buffer strip instigated as an isolated patch alongside a larger stream (c. >2.5 km² upstream catchment size) would increase nutrient export, as the relative amount of nutrients trapped by the buffer decreases as the nutrient load present in the stream water increases. However, in these larger streams with width exceeding approximately 6 m, sufficient light may reach the streambed for plant and algal growth, which in turn would promote instream nutrient processing. At the peak of streambank erosion after planting, predicted total sediment yield (hill slope plus bank sources) was appreciably higher than the hill slope pasture yield, but sediment yield stabilised c. 35-40 years after planting. When planting was extended over 40 years in the model, the sediment yield never exceeded that in pasture before planting. This conceptual modelling exercise shows that riparian tree planting programmes should commence in the headwaters and progress downstream to avoid nutrient yield increases. Significant sediment yield from bank stored sediment of small streams can be expected until the channel reaches the more stable, original forested width, but progressive planting may decrease the peak loads of sediment.

Paetzold, Achim; Yoshimura, Chihiro; Tockner, Klement. (2008). Riparian Arthropod Responses to Flow Regulation and River Channelization, *Journal of Applied Ecology*, Vol. 45, No. 3, 894-903, <http://www.jstor.org/stable/20144043>

Alterations to river flow and morphology widely impact riverine habitats. Little is known about the consequences of such alterations on riparian arthropods, although they contribute substantially to riverine biodiversity and play a critical role in linking aquatic and terrestrial food webs. 2. We investigated the interactive effects of flow regulation (hydropeaking) and river channelization on gravel-bar habitat characteristics and riparian arthropods in seven Alpine rivers. Digital elevation models were developed to simulate inundation dynamics of each gravel bar. Our results indicate that the richness and abundance of riparian arthropods were predominantly affected by the availability of exposed gravel above the average high-water level and substrate embeddedness. Restoration of riverbank morphology and mitigation of hydropeaking are likely to benefit riparian arthropods. Riparian arthropods, particularly spiders and rove beetles, appear to be sensitive indicators of the ecological effects of hydromorphological alterations in rivers.

Pedersen, M. L., Friberg, N., Skriver, J., Baattrup-Pedersen, A., & Larsen, S. E. (2007). Restoration of Skjern River and its valley—Short-term effects on river habitats, macrophytes and macroinvertebrates. *Ecological Engineering*, 145-156.

The lower 19 km of the Skjern River was restored and transformed into a 26 km long meandering river. Three survey reaches and one control reach upstream of the restoration area were surveyed to assess the short-term effects of the restoration on river habitats, macrophytes and macroinvertebrates. The reaches were surveyed before the restoration in 2000 and again after the restoration in 2003. Morphological adjustments were evident in the

re-meandered river and the habitat structure (depth, current velocity and substratum) became more diverse. The macrophyte coverage was 34% before the restoration. Restoration included removal of dense near bank vegetation stands of *Glyceria maxima*, and in 2003 recolonization of the restored reaches had resulted in 24% macrophyte coverage. Species composition and growth patterns changed significantly in the edge habitat and the dominant macrophyte *G. maxima* was replaced by *Elodea canadensis* and *Sparganium* sp. Macroinvertebrates rapidly colonized the restored reaches and increased the community diversity. Only one taxon, Heptageniidae, significantly increased in abundance after the restoration and a more even distribution of taxa developed on the restored reaches. Biological communities will continue to develop over the coming years as the river becomes more physically stable. Hence the macroinvertebrate and macrophyte communities will adjust and colonization from upstream sources and other systems will probably increase biodiversity. (C) 2006 Elsevier B.V. All rights reserved.

Perkins, Dustin W. and Hunter Jr., Malcolm L. (2006). Effects of Riparian Timber Management on Amphibians in Maine, *The Journal of Wildlife Management*, Vol. 70, No. 3, 657-67, <http://www.jstor.org/stable/3803420>

Riparian areas are one of the most complex, diverse, and dynamic environments in forested ecosystems. In areas managed for timber, riparian areas are often protected with unharvested forested buffers, but it is unclear whether these buffers are adequate to maintain the floral and faunal diversity of riparian areas. Amphibians are sensitive to forest management, have high diversity in riparian areas, and are among the most abundant vertebrates in temperate forests; therefore, they are excellent candidates to use in a study of the effects of riparian timber management. We conducted a field experiment with 15 headwater streams in western Maine, USA, randomly assigned to 5 silvicultural treatments. We examined amphibian abundance for 1 year prior to and 2 years following treatment. We also undertook a retrospective study on 12 headwater streams representing 3 treatments where harvests had occurred 4-10 years earlier. We used pitfall traps with drift fences and cover-controlled, active-searches to sample terrestrial and stream amphibians. Wood frogs (*Rana sylvatica*), eastern red-backed salamanders (*Plethodon cinereus*), and spotted salamanders (*Ambystoma maculatum*) were sensitive to timber harvesting along headwater streams. American toads (*Bufo americanus*) were either unaffected or increased in abundance postharvest. Buffers ranging in width from 11 to 35 m appeared to partially mitigate the effects of timber harvest because abundances were generally higher within the buffer than in the adjacent clearcut for wood frogs, American toads, and to a lesser extent red-backed salamanders. Partial harvests adjacent to headwater streams had the least effect on the riparian amphibian community and should be considered for harvests along headwater streams when managing at the stream scale. Our results show that managers can conduct riparian timber harvesting in a manner that allows a diverse suite of amphibian species to persist in the first years after harvest. It is plausible that these same practices may also mitigate the effects of timber harvesting on other forest species. Long-term effects of riparian timber harvesting on amphibians and other forest species population persistence and viability is a logical next step.

Poff, N. L., Allan, J. D., Bain, M. B., Karr, J. R., Prestegard, K. L., Richter, B. D., Stromberg, J. C. (1997). The Natural Flow Regime A paradigm for river conservation and restoration. *BioScience*, 47, 769–784.

Humans have long been fascinated by the dynamism of free-flowing waters. Yet we have expended great effort to tame rivers for transportation, water supply, flood control, agriculture, and power generation. It is now recognized that harnessing of streams and rivers comes at great cost: Many rivers no longer support socially valued native species or sustain healthy ecosystems that provide important goods and services (Naiman et al. 1995, NRC 1992). The extensive ecological degradation and loss of biological diversity resulting from river exploitation is eliciting widespread concern for conservation and restoration of healthy river ecosystems among scientists and the lay public alike (Allan and Flecker 1993, Hughes and Noss 1992, Karr et al. 1985, TNC 1996, Williams (SIC) et al. 1996). Extirpation of species, closures of fisheries, groundwater depletion. Declines in water availability, and more frequent and intense flooding are increasingly recognized as consequences of current river management and development policies (Abramovitz 1996, Collier et al. 1996, Naiman et al. 1995). The broad social support in the United States for the Endangered Species Act, the recognition of the intrinsic value of non-commercial native species, and the proliferation of watershed councils and river watch teams are evidence of society's interest in maintaining the ecological integrity and self-sustaining productivity of free-flowing river systems. Society's ability to maintain and restore the integrity of river ecosystems requires that conservation and management actions be firmly grounded in scientific understanding. However, current management approaches often fail to recognize the fundamental scientific principle that the integrity of flowing water systems depends largely on their natural dynamic character; as a result, these methods frequently prevent successful river conservation or restoration. Stream flow quantity and timing are critical components of water supply, water quality, and the ecological integrity of river systems. Indeed, stream flow, which is strongly correlated with many critical physicochemical characteristics of rivers such as water temperature, channel geomorphology, and habitat diversity, can be considered a "master variable" that limits the distribution and abundance of riverine species (Power et al. 1995, Resh et al. 1988) and regulates the ecological integrity of flowing water systems (Figure 1). Until recently, however, the importance of natural stream flow variability in maintaining healthy aquatic ecosystems has been virtually ignored in a management context.

Pollock, M. M., Beechie, T. J., & Imaki, H. (2012). Using reference conditions in ecosystem restoration: an example for riparian conifer forests in the Pacific Northwest. *Ecosphere*, Volume 3, Issue 11.

Quantifying the attributes of reference sites is a crucial problem in the restoration of ecosystems, driving both the evaluation of current conditions and the setting of management targets for specific points in the future. Restoration of riparian ecosystems, particularly those dominated by conifers, has become a priority because of the numerous ecosystem services they provide, including a high number of vertebrate species in population decline that utilize these structurally complex forests. By way of example, we illustrate a three-step process to assess the effects of proposed riparian ecosystem restoration efforts: (1) identify reference sites (2) quantify metrics that describe the reference sites, and (3) use models to predict the likely effects of restoration actions relative to reference conditions. To this end, we identified 117 natural, late-successional conifer dominated stands from existing forest inventories in the Pacific Northwest for the purpose of establishing reference conditions. We did this to establish quantitative metrics for structural attributes essential to the maintenance of biodiversity in these forests, and to assess whether there were any important quantitative

differences between upland and riparian forests or whether upland and riparian forest reference sites could be used interchangeably. Both forest types were generally similar, but riparian stands had higher average live tree wood volumes and basal areas, suggesting they may be growing on sites that are more productive. Both riparian and upland forests had abundant large diameter (>50 cm) live trees and snags. Collectively, our data suggest that mature, late-successional conifer dominated forests have well developed structural characteristics in terms of abundant large trees in the overstory, abundant large snags, and a well-developed understory of shade-tolerant trees. We modeled the growth of young conifer stands to assess whether a common restoration treatment would accelerate development of structural characteristics typical of reference conditions. We found that left untreated, the stands followed a trajectory towards developing forest structure similar to the average reference condition. In contrast, the restoration treatment followed a developmental trajectory along the outside range of reference conditions.

Polster, D. F. (2002). Soil Bioengineering Techniques for Riparian Restoration. In *Proceedings of the 26th Annual British Columbia Mine Reclamation Symposium in Dawson Creek, BC*, 230–239.

Soil bioengineering is the use of living plant materials to perform some engineering function. Soil bioengineering techniques can be used to treat eroding banks, excess gravel and unstable slopes and can provide a finished product that treats the problem as well as providing appropriate riparian vegetation. The natural successional process associated with development of a healthy, functioning riparian vegetation cover is the model that is used to design repair systems that encourage restoration of riparian values. By providing a living, growing system for repair of damaged sites, possibly with wood and rock, the repair can contribute to living riparian area. Soil bioengineering systems have been used to treat a variety of degraded riparian areas. Live bank protection can be used to form defensive walls of vegetation along the eroding banks of rivers, streams and ponds. Live palisades can be used to re-establish riparian forests quickly. Live gravel bar staking can be used to treat areas where excessive gravel deposits from up-slope erosion threaten downstream channel morphology. Wattle fences, live pole drains, live smiles and a variety of other techniques can be used to treat bank instabilities. This paper presents descriptions of where soil bioengineering treatments have been used for riparian restoration. Examples are drawn from over twenty years of experience by the author.

Qiu, Z. (2009). Assessing critical source areas in watersheds for conservation buffer planning and riparian restoration. *Environmental Management*, 44, 968–980.

A science-based geographic information system (GIS) approach is presented to target critical source areas in watersheds for conservation buffer placement. Critical source areas are the intersection of hydrologically sensitive areas and pollutant source areas in watersheds. Hydrologically sensitive areas are areas that actively generate runoff in the watershed and are derived using a modified topographic index approach based on variable source area hydrology. Pollutant source areas are the areas in watersheds that are actively and intensively used for such activities as agricultural production. The method is applied to the Neshanic River watershed in Hunterdon County, New Jersey. The capacity of the topographic index in predicting the spatial pattern of runoff generation and the runoff contribution to stream flow

in the watershed is evaluated. A simple cost-effectiveness assessment is conducted to compare the conservation buffer placement scenario based on this GIS method to conventional riparian buffer scenarios for placing conservation buffers in agricultural lands in the watershed. The results show that the topographic index reasonably predicts the runoff generation in the watershed. The GIS-based conservation buffer scenario appears to be more cost-effective than the conventional riparian buffer scenarios.

Rood, Stewart B., Braatne, Jeffrey H., Hughes, Francine M.R. (2003). Ecophysiology of riparian cottonwoods: stream flow dependency, water relations and restoration. *Tree Physiology* Vol. 23, p. 1113-1124.

The total production of plant litter and the proportion of leaf litter are higher in riparian corridors than in upland ecosystems throughout the world. Periodical water-level fluctuation is believed to be the major cause of these differences. During flood periods, much plant litter is redistributed locally and between regions, following erosion, transport, and deposition of litter. The importance of litter redistribution varies with factors such as flood regime, topography, and vegetation. Litter from the riparian corridor is usually a major constituent of the litter transported by the river. The decomposition of litter is faster in riparian corridors than in upland systems due to a higher rate of leaching and a higher decomposer activity. Relative warmth and soil fertility may also enhance litter decomposition in riparian corridors. In general, accumulated litter affects plants physically by burying them, chemically by adding nutrients and phytotoxins, and biologically by adding diaspores. The physical impact of a certain amount of litter may be weaker in riparian corridors than in uplands because the rapid decomposition reduces the time that litter is present. In other words, higher amounts of litter are needed to affect riparian vegetation than are needed to affect other types of vegetation. The nutrient content of river borne litter is reduced by leaching, but dissolved nutrients from litter might still reach the riparian vegetation, e.g., by adsorbing to inorganic particles. Phytotoxins are probably unimportant in riparian systems. The input to the riparian corridor of plant diaspores, borne by litter packs in the river, may be large. Indirect biological effects of litter, including its diaspores, are the attracting of animals and microbes that may influence the plant community, and the creation of bare soil for plant colonization.

Rose, Michael and Hermanutz, Luise. (2004) Are Boreal Ecosystems Susceptible to Alien Plant Invasion? Evidence from Protected Areas, *Oecologia*, Vol. 139, No. 3, 467-477, <http://www.jstor.org/stable/40005567>

Although biological invasion by alien species is a major contributor to loss of indigenous biological diversity, few studies have examined the susceptibility of the boreal biome to invasion. Based on studies of other ecosystems, we hypothesized that alien plants will be restricted to disturbed areas near human activity and will not be found in natural areas of boreal ecosystems in Gros Morne National Park (Canada), a protected area experiencing a wide range of disturbance regimes. The distribution of alien plants in the region was evaluated using surveys, and study sites were established in naturally and anthropogenically disturbed habitats that had been invaded. Within study sites, randomization tests evaluated the importance of disturbance to alien plant invasion by examining changes in environmental conditions and species abundance within various disturbance regimes, while the importance

of site characteristics limiting the distribution of alien plants were examined using Canonical Correspondence Analysis. Consistent with studies in a variety of biomes, areas of high disturbance and human activity had the greatest abundance of resources and the highest percentage of alien species. However, contrary to our hypothesis, natural areas of boreal ecosystems were found susceptible to alien plant invasion. Vegetation types vulnerable to invasion include forests, riparian areas, fens, and alpine meadows. Natural disturbance occurring in these vegetation types caused increases in bare ground and/or light availability facilitating alien plant invasion. Although high soil pH was associated with alien plants in these areas, disturbance was not found to cause changes in soil pH, suggesting susceptibility to invasion is predetermined by bedrock geology or other factors influencing soil pH. Moose (*Alces alces*), a non-native herbivore, acts as the primary conduit for alien plant invasion in GMNP by dispersing propagules and creating or prolonging disturbance by trampling and browsing vegetation. The recurrent nature of disturbance within the boreal biome and its interaction with site conditions and herbivores enables alien plants to persist away from areas of high human activity. Managers of natural lands should monitor such interactions to decrease the invasion potential of alien plants.

Renöfält, B.M.; C. Nilsson; R. Jansson. (2005). Spatial and Temporal Patterns of Species Richness in a Riparian Landscape, *Journal of Biogeography*, Vol. 32, No. 1, 2025-2037, <http://www.jstor.org/stable/3566296>

Aim To test for control of vascular plant species richness in the riparian corridor by exploring three contrasting (although not mutually exclusive) hypotheses: (1) longitudinal patterns in riparian plant species richness are governed by local, river-related processes independent of the regional species richness, (2) riparian plant species richness is controlled by dispersal along the river (longitudinal control), and (3) the variation in riparian plant species richness mirrors variation in regional richness (lateral control). **Location:** The riparian zones of the free-flowing Vindel River and its surrounding river valley, northern Sweden. **Methods:** We used data from three surveys, undertaken at 10-year intervals, of riparian reaches (200-m stretches of riverbank) spanning the entire river. In addition, we surveyed species richness of vascular plants in the uplands adjacent to the river in 3.75-km² large plots along the same regional gradient. We explored the relationship between riparian and upland flora, and various environmental variables. We also evaluated temporal variation in downstream patterns of the riparian flora. **Results:** Our results suggest that local species richness in boreal rivers is mainly a result of local, river-related processes and dispersal along the corridor. The strongest correlation between species richness and the environment was a negative one between species number and soil pH, but pH varied within a narrow range. We did not find evidence for a correlation between species richness on regional and local scales. We found that the local patterns of species richness for naturally occurring vascular plants were temporally variable, probably in response to large-scale disturbance caused by extreme floods. Most previous studies have found a unimodal pattern of species richness with peaks in the middle reaches of a river. In contrast, on two of three occasions corresponding to major flooding events, we found that the distribution of species richness of naturally occurring vascular plants resembled that of regional diversity: a monotonic decrease from headwater to coast. We also found high floristic similarity between the riparian corridor and the surrounding landscape. **Main conclusions:** These results suggest that local processes control patterns of riparian species richness, but that species composition

is also highly dependent on the regional species pool. We argue that inter-annual variation in flood disturbance is probably the most important factor producing temporal variability of longitudinal species richness patterns.

Renöfält, B.M.; Nilsson, C., Nilsson; Jansson, R. (2007) Connecting Variation in Vegetation and Stream Flow: The Role of Geomorphic Context in Vegetation Response to Large Floods along Boreal Rivers, *Journal of Applied Ecology*, Vol. 44, No. 1, 147-157, <http://www.jstor.org/stable/4123833>

Flooding governs riparian plant diversity along boreal rivers but the ecological role of extreme floods is only partly understood. We studied the dynamics of riparian plant composition and richness in the free-flowing Vindel River in northern Sweden, and the importance of reach type in sustaining high species richness. We conducted three surveys of riparian plant species richness over a period of two decades. The first and last of these surveys were conducted 1-3 years after significant flooding and the second was carried out after a period of more moderate flooding. Our results suggest that extreme floods reduce riparian plant species richness in tranquil (slow-flowing) reaches but that a subsequent period of less extreme flood events facilitates recovery. Tranquil river reaches were also more prone to invasion by ruderal species following major floods. Species richness in turbulent reaches (rapids and runs) remained constant during all surveys. One possible explanation for this pattern is that tranquil reaches become more anoxic during floods because they have more fine-grade soils with lower hydraulic conductivity than turbulent reaches. Anoxic conditions may cause stress and plant death, opening up space for colonization. Turbulent reaches maintain a better oxygenation in the root zone of plants through high groundwater turnover, reducing negative effects of prolonged floods. The fact that turbulent reaches preserved species richness regardless of flood magnitude suggests that they are important for the resistance of riparian ecosystems to prolonged inundation. In contrast, tranquil reaches, with a higher water-holding capacity, might instead maintain their species richness during drought periods. Synthesis and applications. Our findings highlight the importance of spatial and temporal variation in riverine plant species richness and composition. To conserve these habitats at a landscape scale, a full range of reach types is necessary to allow for recovery in reaches where species richness has declined. To maintain healthy riparian zones, river managers should focus restoration efforts on interactions between hydrology, geomorphology and biota.

Rohde, S., Schutz, M., Kienast, F., & Englmaier, P. (2005). River widening: An approach to restoring riparian habitats and plant species. *River Research and Applications*, 21, 1075–1094.

River widenings are commonly used in river restoration to allow channel movement within a spatially limited area. Restoration seeks to restore fluvial processes and to re-establish a more natural riparian community. This study investigates the performance of five river widenings in Switzerland, focusing on the re-establishment of riparian and terrestrial habitats and species, and highlights some factors that seem to influence their performance. The restoration projects are compared with pre-restoration conditions and near-natural

conditions, which are assumed to represent the worst- and best-case conditions along a gradient of naturalness. Fuzzy ordination of vegetation data and calculation of landscape metrics based on habitat maps revealed marked differences between the degree of naturalness achieved by each individual restoration project. However, in C general river widenings were found to increase the in-stream habitat heterogeneity and enhanced the establishment of pioneer habitats and riparian plants. Analyses of species pools based on a hierarchic list of indicator species and correspondence analysis showed that the ability of river widenings to host typical riparian species and to increase local plant diversity strongly depends on the distance to near-natural stretches. Species dispersal and establishment might be hampered by decisions taken outside the scope of the restoration project. Therefore we conclude that action\on the catchment scale is needed to maximize the benefits of local management.

Roni, P., Beechie, Timothy, J., Bilby, Robert, E., Leonetti, Frank, E., Pollock, Micheal, M., & Pess, George, R. (2002). A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in pacific northwest watersheds. *North American Journal of Fisheries Management*, 22, 1–20.

Millions of dollars are spent annually on watershed restoration and stream habitat improvement in the U.S. Pacific Northwest in an effort to increase fish populations. It is generally accepted that watershed restoration should focus on restoring natural processes that create and maintain habitat rather than manipulating instream habitats. However, most process-based restoration is site-specific, that is, conducted on a short stream reach. To synthesize site-specific techniques into a process-based watershed restoration strategy, we reviewed the effectiveness of various restoration techniques at improving fish habitat and developed a hierarchical strategy for prioritizing them. The hierarchical strategy we present is based on three elements: (1) principles of watershed processes, (2) protecting existing high-quality habitats, and (3) current knowledge of the effectiveness of specific techniques. Initially, efforts should focus on protecting areas with intact processes and high-quality habitat. Following a watershed assessment, we recommend that restoration focus on reconnecting isolated high-quality fish habitats, such as instream or off-channel habitats made inaccessible by culverts or other artificial obstructions. Once the connectivity of habitats within a basin has been restored, efforts should focus on restoring hydrologic, geologic (sediment delivery and routing), and riparian processes through road decommissioning and maintenance, exclusion of livestock, and restoration of riparian areas. Instream habitat enhancement (e.g., additions of wood, boulders, or nutrients) should be employed after restoring natural processes or where short-term improvements in habitat are needed (e.g., habitat for endangered species). Finally, existing research and monitoring is inadequate for all the techniques we reviewed, and additional, comprehensive physical and biological evaluations of most watershed restoration methods are needed. Watershed

Russeff, G. D., Hawkins, C. P., & Neiff, M. P. O. (1997). The Role of GIs in Selecting Sites for Riparian Restoration Based on Hydrology and Land Use. *Restoration Ecology*, 5, 56–68.

Successful long-term wetland restoration efforts require consideration of hydrology and surrounding land use during the site selection process. This article describes an approach to initial site selection in the San Luis Rey River watershed in southern California that uses

watershed-level information on basin topography and land cover to rank the potential suitability of all sites within a watershed for either preservation or restoration. This approach requires the use of a geographic information system (GIS) to map relative wetness and land cover within a watershed. Relative potential wetness values were derived from U.S. Geological Survey (USGS) 30-m digital elevation models by calculating the flow that would potentially accumulate at all 30-m X 30-m pixels within the watershed. Land cover was derived from a Landsat scene covering the 1500 km² study area. We ranked sites (contiguous groups of pixels > 1 ha with similar land cover) in terms of their potential for restoration or preservation based on their wetness values (low, medium, and high), size, and proximity to existing riparian vegetation. Sites with medium or high wetness values and extant vegetation were identified as potential preservation sites. Agricultural or barren sites with medium to high wetness were identified as potential restoration sites. Approximately 5500 ha (3.67% of the total watershed) were prioritized for preservation or restoration.

Salemi, L. F., Groppo, J. D., Trevisan, R., Marcos de Moraes, J., de Paula Lima, W., & Martinelli, L. A. (2012). Riparian vegetation and water yield: A synthesis. *Journal of Hydrology*. Volumes 454–455, 195–202.

Forested riparian zones perform numerous ecosystem functions, including the following: storing and fixing carbon; serving as wildlife habitats and ecological corridors; stabilizing streambanks; providing shade, organic matter, and food for streams and their biota; retaining sediments and filtering chemicals applied on cultivated/agricultural sites on upslope regions of the catchments. In this paper, we report a synthesis of a different feature of this type of vegetation, which is its effect on water yield. By synthesizing results from studies that used (i) the nested catchment and (ii) the paired catchment approaches, we show that riparian forests decrease water yield on a daily to annual basis. In terms of the treated area increases on average were $1.32 \pm 0.85 \text{ mm day}^{-1}$ and $483 \pm 309 \text{ mm yr}^{-1}$, respectively; $n=9$. Similarly, riparian forest plantation or regeneration promoted reduced water yield (on average $1.25 \pm 0.34 \text{ mm day}^{-1}$ and $456 \pm 125 \text{ mm yr}^{-1}$ on daily and annual basis, respectively, when prorated to the catchment area subjected to treatment; $n=5$). Although there are substantially fewer paired catchment studies assessing the effect of this vegetation type compared to classical paired catchment studies that manipulate the entire vegetation of small catchments, our results indicate the same trend. Despite the occurrence of many current restoration programs, measurements of the effect on water yield under natural forest restoration conditions are still lacking. We hope that presenting these gaps will encourage the scientific community to enhance the number of observations in these situations as well as produce more data from tropical regions.

Scheiechtl, H.M. and R. Stern, Water Bioengineering Techniques for Watercourse Bank and Shoreline Protection, 1994. *Book distributed by Copp Clark Professional*, 200 Adelaide St, west, third floor, Toronto, Ontario M5H 1W7 1-800-815-9417, ISBN 0-632-04066-1

Translated from German this is a practical handbook for using vegetation for protection, stabilization and ecological enhancement of riparian areas. It covers soft to semi hard techniques, includes chapter on dams and flood management.

Seavy, N. E., Gardali, T., Golet, G. H., Griggs, F. T., Howell, C. A., Kelsey, R., Weigand, J. F. (2009). Why Climate Change Makes Riparian Restoration More Important than Ever: Recommendations for Practice and Research. *Ecological Restoration*. Vol. 27, No. 3, 330-338.

Over the next century, climate change will dramatically alter natural resource management. Specifically, historical reference conditions may no longer serve as benchmarks for restoration, which may foster a "why bother?" attitude toward ecological restoration. We review the potential role for riparian restoration to prepare ecological systems for the threats posed by climate change. Riparian ecosystems are naturally resilient, provide linear habitat connectivity, link aquatic and terrestrial ecosystems, and create thermal refugia for wildlife: all characteristics that can contribute to ecological adaptation to climate change. Because riparian systems and the projected impacts of climate change are highly variable geographically, there is a pressing need to develop a place-based understanding of climate change threats to riparian ecosystems. Restoration practitioners should consider how they can modify practices to enhance the resilience of riparian ecosystems to climate change. Such modifications may include accelerating the restoration of private lands, participating in water management decisions, and putting the emerging field of restoration genetics into practice.

Sieben, E. J. J., & Reinecke, M. K. (2008). Description of reference conditions for restoration projects of riparian vegetation from the species-rich fynbos biome. *South African Journal of Botany*, 74, 401–411.

When considering revegetation strategies for particular restoration projects, data on community composition and structure should, whenever possible, be obtained from reference sites. Revegetation is an important restoration strategy especially since riverbanks that have been cleared of alien vegetation are extremely susceptible to erosion. The presence of lateral zonation in riparian vegetation is well documented: flooding events shape the vegetation on riverbanks and the zones that are inundated annually have different vegetation than those that are inundated interannually. This can be referred to as the demerse ecotope, or Wet Bank, and the emerse ecotope, or Dry Bank, and these zones can also be further subdivided. There is a need for species descriptions from undisturbed riparian zones to guide post-project appraisal and revegetation strategies, especially in areas with high species turnover like the fynbos biome. Braun-Blanquet vegetation belt transects were sampled on five undisturbed rivers that originate in the Hottentots Holland mountain range. Relevés were sampled from as many Wet Bank and Dry Bank subzones as were present in each case. Twenty-six riparian communities were recognized, which were clustered into ten community Groups based on physical bank attributes. The most dominant species for each of these community types have been listed in a synoptic table that can be used for revegetation purposes. It is recommended that revegetation plans make use of a mixture of the listed species, whilst maintaining separation of Wet and Dry Bank species. Prior to species selection, it is necessary to assess the range of riparian habitats available in the project reach. Though revegetation is more expensive than allowing for natural recruitment, recent evidence has shown that recovery of the natural vegetation without intervention may be limited, and not without risks. Revegetation may be a cheaper strategy in the long term, avoiding the maintenance costs that are required to stabilize banks and to remove re-invading alien species.

Simmons, M. E., Wu, X. Ben, & Whisenant, S. G. (2012). Responses of Pioneer and Later-Successional Plant Assemblages to Created Microtopographic Variation and Soil Treatments in Riparian Forest Restoration. *Restoration Ecology*, 20, 369–377.

Riparian forest restoration generally involves introduction of later-successional tree species, but poor species suitability to severely altered or degraded site conditions results in high mortality and poor community development. Additionally, while micro-topographic heterogeneity plays a crucial role in the development of natural riparian forests, little is known regarding effects of restored or created micro-topography on the development of introduced plant communities. The objective of this study was to determine the influence of created micro-topography and soil treatments on early development of introduced pioneer and later-successional plant communities in riparian forest restoration. Ridges, flats, and a mound-and-pool complex were created, and pioneer and later-successional tree assemblages were planted within plots in each of these three micro-topographic positions. Straw-based erosion control mats were placed on half the plots as a source of mulch. After two growing seasons, growth and survival of the pioneer assemblage were equal among micro-topographic positions, but survival of the later-successional assemblage was significantly higher on ridges (59%) than on mounds and pools (22%) and flats (26%). A suitability index indicated that performance of the later-successional assemblage on ridges was higher than that of the pioneer assemblage for all micro-topographic positions. Flood duration explained much of the variation in plant assemblage survival, and erosion control mats had little influence on seedling survival. Restoring micro-topographic features has the potential to enhance species survival and promote community development. Micro-topographic restoration may be as important in riparian forest restoration as proper species selection and hydrologic reestablishment, especially at severely disturbed sites.

Simon, A., & Collison, A. J. C. (2002). Quantifying the mechanical and hydrologic effects of riparian vegetation on streambank stability. *Earth Surface Processes and Landforms*, 27, 527–546.

Riparian vegetation strips are widely used by river managers to increase streambank stability, among other purposes. However, through the effects of Vegetation on bank stability are widely discussed they are rarely quantified, and generally underemphasize the importance of hydrologic processes, some of which may be detrimental. This paper presents results from an experiment in which the hydrologic and mechanical effects of four riparian tree species and two erosion-control grasses were quantified in relation to bank stability. Geotechnical and pore-water pressure data from stream bank plots under three riparian covers (mature trees, clump grasses and bare/cropped turf grass) were used to drive the ARS bank stability model, and the resulting factor of safety (F-s) was broken down into its constituent parts to assess the contribution (beneficial or detrimental) of individual hydrologic and mechanical effects (soil moisture modification, root reinforcement and Surcharge). Tree roots were found to increase soil strength by 2-8 kPa depending on species, while grass roots contributed 6-18 kPa. Slope stability analysis based on data collected during bank failures in spring 2000 (following a very dry antecedent period) shows that the mechanical effects of the tree cover increased F-s by 32 per cent, while the hydrologic effects increased F-s by 71 per cent. For grasses the figures were 70 per cent for mechanical effects and a reduction of F-s by 10 per cent for the hydrologic effects. However, analysis

based on bank failures in spring 2001 (following a wetter than average antecedent period) showed the mechanical effects of the tree cover to increase F-s by 46 per cent, while hydrologic effects added 29 per cent. For grasses the figures were 49 per cent and -15 per cent respectively. During several periods in spring 2001 the hydrologic effects of the tree cover reduced bank stability, though this was always offset by the stabilizing mechanical effects. The results demonstrate the importance of hydrologic processes in controlling streambank stability, and highlight the need to select riparian vegetation based on hydrologic as well as mechanical and ecological criteria, Published in 2002 by John Wiley Sons, Ltd.

Steiger, J., Tabacchi, E., Dufour, S., Corenblit, D., & Peiry, J. L. (2003). Hydrogeomorphic processes affecting riparian habitat within alluvial channel-floodplain river systems: A review for the temperate zone. In *Workshop on Sediment Management River Systems*, 719–737.
<http://onlinelibrary.wiley.com/doi/10.1002/rra.879/abstract;jsessionid=14FBF57556787DD09855F01F2247C7EF.f02t01>

Hydrogeomorphic processes within alluvial river systems create, maintain and degrade riparian habitat. The dynamic interactions between water, sediment, aquatic-terrestrial landforms and biotic elements control the functional processes and biodiversity patterns within the riparian zone and, thus, contribute directly to their ecological integrity and societal value. Numerous researchers from different disciplines publish work on the physical, biological, economic and societal functions of the riparian zone within various physiographic areas. The present paper aims to review the hydrogeomorphic processes of unconfined alluvial channel-floodplain rivers within the temperate zone. These processes and their interactions with the biotic environment provide the basis for understanding the physical as well as the ecological functioning of fluvial hydrosystems. The review focuses mainly on the European context, but major advances in riparian research from other continents are also considered. Rehabilitation and management strategies for the riparian zone are summarized and recommendations for further research conclude this review.

Sundermann, A., Stoll, S., & Haase, P. (2011). River restoration success depends on the species pool of the immediate surroundings. *Ecological Applications*, Vol. 21, Issue 26, 1962-1971.

Previous studies evaluating the success of river restorations have rarely found any consistent effects on benthic invertebrate assemblages. In this study, we analyzed data from 24 river restoration projects in Germany dating back 1 to 12 years and 1231 data sets from adjacent river reaches that lie within 0-5, 5-10, and 10-15 km rings centered on the restored sites. We calculated restoration success and recolonization potential of adjacent river reaches based on stream-type-specific subsets of taxa indicative for good or bad habitat quality. On average, the restorations did not improve the benthic invertebrate community quality. However, we show that restoration success depends on the presence of source populations of desired taxa in the surrounding of restored sites. Only where source populations of additional desired taxa existed within a 0-5 km ring around the restored sites were benthic invertebrate assemblages improved by the restoration. Beyond the 5-km rings, this recolonization effect was no longer detected. We present here the first field results to support the debated argument that a lack of source populations in the areas surrounding restored sites may play an important role in the failure to establish desired invertebrate communities by the means of river restorations. In

contrast, long-range dispersal of invertebrates seems to play a subordinate role in the recolonization of restored sites. However, because the surroundings of the restored sites were far from good ecological quality, the potential for improvement of restored sites was limited.

Sweeney, B. W., Bott, T. L., Jackson, J. K., Kaplan, L. A., Newbold, J. D., Standley, L. J., Horwitz, R. J. (2004). Riparian deforestation, stream narrowing, and loss of stream ecosystem services. *Proceedings of the National Academy of Sciences of the United States of America*, 101, 14132–14137.

A study of 16 streams in eastern North America shows that riparian deforestation causes channel narrowing, which reduces the total amount of stream habitat and ecosystem per unit channel length and compromises in-stream processing of pollutants. Wide forest reaches had more macroinvertebrates, total ecosystem processing of organic matter, and nitrogen uptake per unit channel length than contiguous narrow deforested reaches. Stream narrowing nullified any potential advantages of deforestation regarding abundance of fish, quality of dissolved organic matter, and pesticide degradation. These findings show that forested stream channels have a wider and more natural configuration, which significantly affects the total in-stream amount and activity of the ecosystem, including the processing of pollutants. The results reinforce both current policy of the United States that endorses riparian forest buffers as best management practice and federal and state programs that subsidize riparian reforestation for stream restoration and water quality. Not only do forest buffers prevent nonpoint source pollutants from entering small streams, they also enhance the in-stream processing of both nonpoint and point source pollutants, thereby reducing their impact on downstream rivers and estuaries.

Sweeney, B. W., Czapka, S. J., & Yerkes, T. (2002). Riparian Forest Restoration: Increasing Success by Reducing Plant Competition and Herbivory. *Restoration Ecology*, 10, 392–400.

The reestablishment of riparian forest is often viewed as "best management practice" for restoring stream ecosystems to a quasi-natural state and preventing non-point source contaminants from entering them. We experimentally assessed seedling survivorship and growth of *Quercus palustris* (pin oak), *Q. rubra* (red oak), *Q. alba* (white oak), *Betula nigra* (river birch), and *Acer rubrum* (red maple) in response to root-stock type (bare root vs. containerized), herbivore protection (tree shelters), and weed control (herbicide, mowing, tree mats) over a 4-year period at two riparian sites near the Chester River in Maryland, U.S.A. We started with tree-stocking densities of 988/ha (400/ac) in the experimental plots and considered 50% survivorship (i.e., a density of 494/ha 200/ac at crown closure) to be an "acceptable or minimum" target for riparian restoration. Results after four growing seasons show no significant difference in survivorship and growth between bare-root and containerized seedlings when averaged across all species and treatments. Overall survivorship and growth was significantly higher for sheltered versus unsheltered seedlings (49% and 77.6 cm vs. 12.1% and 3.6 cm, respectively) when averaged across all species and weed control treatments. Each of the five test species exhibited significantly higher 4-year growth with shelter protection when averaged across all other treatments, and all species but river birch had significantly higher survivorship in shelters during the period. Seedlings protected from weeds by herbicide exhibited significantly higher survivorship and growth than seedlings in all other weed-control treatments when averaged across all species and

shelter treatments. The highest 4-year levels of survivorship/growth, when averaged across all species, was associated with seedlings protected by shelters and herbicide (88.8%/125.7cm) and by shelters and weed mats (57.5%/73.5 cm). Thus, only plots where seedlings were assisted by a combination of tree shelters and either herbicide or tree mats exhibited an "acceptable or minimum" rate of survivorship (i.e., >50%) for riparian forest restoration in the region. Moreover, the combined growth and survivorship data suggest that crown closure over most small streams in need of restoration in the region can be achieved most rapidly (i.e., 15 years or less) by protecting seedlings with tree shelters and controlling competing vegetation with herbicides.

Tunstall, S. M., Penning-Rowsell, E. C., Tapsell, S. M., & Eden, S. E. (2000). River restoration: public attitudes and expectations. *Water and Environment*, 14, 363–370.

Public attitudes to restoration works on three rivers have been assessed using questionnaires and in-depth inter-views with local residents and restoration-scheme managers, which were carried out after the implementation of the schemes. The results indicate that the restored rivers were well used and highly valued by the local public. At all three sites, the residents approved of the restoration work, and at two sites they considered that the schemes offered 'value for money'. There were differences in the responses to the schemes at the different locations. The research suggests that greater benefits may be perceived in restoring urban rivers such as the Skerne. Local residents attached importance to public consultation and expected to be consulted about river-restoration works. On the basis of the three case studies and on the experiences of restoration practitioners, conclusions are drawn regarding consultation and involving local people in restoring and enhancing rivers.

Walters, C. (1997). Challenges in adaptive management of riparian and coastal ecosystems. *Conservation Ecology [online]*, 1, 1.

Many case studies in adaptive-management planning for riparian ecosystems have failed to produce useful models for policy comparison or good experimental management plans for resolving key uncertainties. Modeling efforts have been plagued by difficulties in representation of cross-scale effects (from rapid hydrologic change to long-term ecological response), lack of data on key processes that are difficult to study, and confounding of factor effects in validation data. Experimental policies have been seen as too costly or risky, particularly in relation to monitoring costs and risk to sensitive species. Research and management stakeholders have shown deplorable self-interest, seeing adaptive-policy development as a threat to existing research programs and management regimes, rather than as an opportunity for improvement. Proposals for experimental management regimes have exposed and highlighted some really fundamental conflicts in ecological values, particularly in cases in which endangered species have prospered under historical management and would be threatened by ecosystem restoration efforts. There is much potential for adaptive management in the future, if we can find ways around these barriers.

Watanabe, Michio, Adams, Richard M., Wu, JunJie, Bolte, John P., Cox, Matt M., Johnson, Sherri L., Liss, William J., Boggess, William G., Ebersole, Joseph L. (2005). Toward efficient riparian restoration: Integrating economic, physical, and biological models. *Journal of Environmental Management*, 75, 93–104.

This paper integrates economic, biological, and physical models to explore the efficient combination and spatial allocation of conservation efforts to protect water quality and increase salmonid populations in the Grande Ronde basin, Oregon. We focus on the effects of shade on water temperatures and the subsequent impacts on endangered juvenile salmonid populations. The integrated modeling system consists of a physical model that links riparian conditions and hydrological characteristics to water temperature; a biological model that links water temperature and riparian conditions to salmonid abundance, and an economic model that incorporates both physical and biological models to estimate minimum cost allocations of conservation efforts. Our findings indicate that conservation alternatives such as passive and active riparian restoration, the width of riparian restoration zones, and the types of vegetation used in restoration activities should be selected based on the spatial distribution of riparian characteristics in the basin. The relative effectiveness of passive and active restoration plays an important role in determining the efficient allocations of conservation efforts. The time frame considered in the restoration efforts and the magnitude of desired temperature reductions also affect the efficient combinations of restoration activities. If the objective of conservation efforts is to maximize fish populations, then fishery benefits should be directly targeted. Targeting other criterion such as water temperatures would result in different allocations of conservation efforts, and therefore are not generally efficient. © 2005 Elsevier Ltd. All rights reserved.

Williams, K. S. (1993). Use of terrestrial arthropods to evaluate restored riparian woodlands. *Restoration Ecology*, 1, 107–116.

Insect communities developed rapidly at the restored habitat. Although the abundance of all arthropods was lower at the reconstructed site than at the reference site, the same orders were present after three years in similar proportions at both locations and mean abundances were within an order of magnitude of each other. Abundance of certain groups, such as detritivores, suggested that arthropods had propagated rapidly at the restoration site, a possible indication of resiliency. Relatively low numbers of other arthropods, such as predators and parasites, at the reconstructed site indicated the need for continued monitoring.

Williams, L., Hale, R., Cavagnaro, T., Reich, P., & Lake, P.S. (2011). Developing a vision for improved monitoring and reporting of riparian restoration projects. *Ecological Management Restoration*, 12, e11–e16.

Representatives from agencies involved in natural resource management in the Murray-Darling Basin gathered for a workshop in November 2010 to develop a vision for improved monitoring and reporting of riparian restoration projects. The resounding message from this workshop was that the effectiveness of riparian restoration depends on having sound, documented and agreed evidence on the ecological responses to restoration efforts. Improving our capacity to manage and restore riparian ecosystems is constrained by (i) a lack of ecological evidence on the effects of restoration efforts, and (ii) short-termism in commitment to restoration efforts, in funding of monitoring and in expected time spans for ecosystem recovery. Restoration at the effective spatial scope will invariably require a long-term commitment by researchers, funding agencies, management agencies and landholders. To address the knowledge gaps that constrain riparian restoration in the Basin, participants endorsed four major fields for future research: the importance of landscape context to

restoration outcomes; spatio-temporal scaling of restoration outcomes; functional effects of restoration efforts; and developing informative and effective indicators of restoration. To improve the monitoring and restoration of riparian zones throughout the Basin, participants advocated an integrated approach: a hierarchical adaptive management framework that incorporates long-term ecological research.

Wohl, E., Angermeier, P. L., Bledsoe, B., Kondolf, G. M., MacDonnell, L., Merritt, D. M., Tarboten, D. (2005). River restoration. *Water Resources Research*, 41, 1-12.

River restoration is at the forefront of applied hydrologic science. However, many river restoration projects are conducted with minimal scientific context. We propose two themes around which a research agenda to advance the scientific basis for river restoration can be built. First, because natural variability is an inherent feature of all river systems, we hypothesize that restoration of process is more likely to succeed than restoration aimed at a fixed end point. Second, because physical, chemical, and biological processes are interconnected in complex ways across watersheds and across timescales, we hypothesize that restoration projects are more likely to be successful in achieving goals if undertaken in the context of entire watersheds. To achieve restoration objectives, the science of river restoration must include (1) an explicit recognition of the known complexities and uncertainties, (2) continued development of a theoretical framework that enables us to identify generalities among river systems and to ask relevant questions, (3) enhancing the science and use of restoration monitoring by measuring the most effective set of variables at the correct scales of measurement, (4) linking science and implementation, and (5) developing methods of restoration that are effective within existing constraints. Key limitations to river restoration include a lack of scientific knowledge of watershed-scale process dynamics, institutional structures that are poorly suited to large-scale adaptive management, and a lack of political support to re-establish delivery of the ecosystem amenities lost through river degradation. This paper outlines an approach for addressing these shortcomings.

Woolsey, S., Capelli, F., Gonser, T., Hoehn, E., Hostmann, M., Junker, B., Peter, A. (2007). A strategy to assess river restoration success. *Freshwater Biology*, 52, 752–769.

Elaborate restoration attempts are underway worldwide to return human-impacted rivers to more natural conditions. Assessing the outcome of river restoration projects is vital for adaptive management, evaluating project efficiency, optimising future programmes and gaining public acceptance. An important reason why assessment is often omitted is lack of appropriate guidelines. Here we present guidelines for assessing river restoration success. They are based on a total of 49 indicators and 13 specific objectives elaborated for the restoration of low- to mid-order rivers in Switzerland. Most of these objectives relate to ecological attributes of rivers, but socio-economic aspects are also considered. A strategy is proposed according to which a set of indicators is selected from the total of 49 indicators to ensure that indicators match restoration objectives and measures, and that the required effort for survey and analysis of indicators is appropriate to the project budget. Indicator values are determined according to methods described in detailed method sheets. Restoration success is evaluated by comparing indicator values before and after restoration measures have been undertaken. To this end, values are first standardised on a dimensionless scale

ranging from 0 to 1, then averaged across different indicators for a given project objective, and finally assigned to one of five overall success categories. To illustrate the application of this scheme, a case study on the Thur River, Switzerland, is presented. Seven indicators were selected to meet a total of five project objectives. The project was successful in achieving 'provision of high recreational value', 'lateral connectivity' and 'vertical connectivity' but failed to meet the objectives 'morphological and hydraulic variability' and 'near natural abundance and diversity of fauna'. Results from this assessment allowed us to identify potential deficits and gaps in the restoration project. To gain information on the sensitivity of the assessment scheme would require a set of complementary indicators for each restoration objective.

Wunderlich, R. C., Winter, B. D., & Meyer, J. H. (1994). Restoration of the Elwha River Ecosystem. *Fisheries*. Vol. 19, No. 8, 11-19.

Historically, the Elwha River in western Washington was renowned for an abundance and diversity of anadromous salmonids. Most of the river system lies within Olympic National Park and remains in pristine condition, but two dams in the lower river have blocked all anadromous fish for more than 80 years. To restore the Elwha's historic fishery resources and resolve an impasse about federal licensing of the dams, the U.S. Congress passed the Elwha River Ecosystem and Fisheries Restoration Act in 1992. The act required an analysis of alternatives (dam retention with fish passage facilities v dam removal) to achieve full ecosystem and fishery restoration. Analysis indicates that removal of both dams is the only option that will achieve full restoration, but dam removal and fish restoration efforts could span 20 years and cost from US\$147 million to US\$203 million. Although fish restoration poses problems because of limited native runs, sediment management presents the most significant environmental challenge and cost. Nevertheless, a unique opportunity to fully restore the ecosystem of a major anadromous-salmonid-producing river is at hand.

Xiong, Shaojun and Nilsson, Christer. (1997). Dynamics of Leaf Litter Accumulation and Its Effects on Riparian Vegetation: A Review, *Botanical Review*, Vol. 63, No. 3, 240-264, <http://www.jstor.org/stable/4354302>

The total production of plant litter and the proportion of leaf litter are higher in riparian corridors than in upland ecosystems throughout the world. Periodical water-level fluctuation is believed to be the major cause of these differences. During flood periods, much plant litter is redistributed locally and between regions, following erosion, transport, and deposition of litter. The importance of litter redistribution varies with factors such as flood regime, topography, and vegetation. Litter from the riparian corridor is usually a major constituent of the litter transported by the river. The decomposition of litter is faster in riparian corridors than in upland systems due to a higher rate of leaching and a higher decomposer activity. Relative warmth and soil fertility may also enhance litter decomposition in riparian corridors. In general, accumulated litter affects plants physically by burying them, chemically by adding nutrients and phytotoxins, and biologically by adding diaspores. The physical impact of a certain amount of litter may be weaker in riparian corridors than in uplands because the rapid decomposition reduces the time that litter is present. In other words, higher amounts of litter are needed to affect riparian vegetation than are needed to affect other types of vegetation. The nutrient content of riverborne litter is reduced by

leaching, but dissolved nutrients from litter might still reach the riparian vegetation, e.g., by adsorbing to inorganic particles. Phytotoxins are probably unimportant in riparian systems. The input to the riparian corridor of plant diaspores, borne by litter packs in the river, may be large. Indirect biological effects of litter, including its diaspores, are the attracting of animals and microbes that may influence the plant community, and the creation of bare soil for plant colonization.

Young, J.S., Ammon, E.M., Weisberg, P.J., Dilts, T. E., Newton, W. E., Wong-Kone, D.C., & Heki, L.G. (2013). Comparison of bird community indices for riparian restoration planning and monitoring. *Ecological Indicators*, 34, 159–167.

The use of a bird community index that characterizes ecosystem integrity is very attractive to conservation planners and habitat managers, particularly in the absence of any single focal species. In riparian areas of the western USA, several attempts at arriving at a community index signifying a functioning riparian bird community have been made previously, mostly resorting to expert opinions or national conservation rankings for species weights. Because extensive local and regional bird monitoring data were available for Nevada, we were able to develop three different indices that were derived empirically, rather than from expert opinion. We formally examined the use of three species weighting schemes in comparison with simple species richness, using different definitions of riparian species assemblage size, for the purpose of predicting community response to changes in vegetation structure from riparian restoration. For the three indices, species were weighted according to the following criteria: (1) the degree of riparian habitat specialization based on regional data, (2) the relative conservation ranking of landbird species, and (3) the degree to which a species is under-represented compared to the regional species pool for riparian areas. To evaluate the usefulness of these indices for habitat restoration planning and monitoring, we modeled them using habitat variables that are expected to respond to riparian restoration efforts, using data from 64 sampling sites in the Walker River Basin in Nevada and California. We found that none of the species-weighting schemes performed any better as an index for evaluating overall habitat condition than using species richness alone as a community index. Based on our findings, the use of a fairly complete list of 30-35 riparian specialists appears to be the best indicator group for predicting the response of bird communities to the restoration of riparian vegetation. © 2013 Published by Elsevier Ltd.

Grey material

Allen, Hollis H. and Leech, James R. (1997). Bioengineering for Streambank Erosion Control, Report 1 Guidelines, *U.S. Army Corps of Engineers*, Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS, DC 20314-1000, (Technical report ; EL-97-8 rept. 1), 103 p.

This report synthesizes information related to bioengineering applications and provides preliminary planning and design guidelines for use of bioengineering treatments on eroded streambanks. It can be used by both planning and design elements, not as a cookbook, but as a guide with tools to accomplish bioengineering projects. It presents a bioengineering design model with examples in the text that describe specific case studies where certain stream

conditions, such as velocities, have been provided. It also describes appropriate plants to use, their acquisition, and their handling requirements. This study is divided into two reports. The main report, Report 1, provides bioengineering guidelines for streambank erosion control. Report 2 presents several case studies of bioengineering treatments applied to one or more streams in various geographic locations around the continental United States.

Becker, H. (2002). Soaking willow cuttings helps them protect streambanks. *USDA Agricultural Research Service National Sedimentation Laboratory*. Oxford, Mississippi (contact person: F. Douglas Shields Jr. shields@sedlab.olemiss.edu).

Soaking willow cuttings gives them a head start in protecting eroding stream banks. Channel erosion is a serious problem in many areas. For years, researchers have tried to stabilize streambanks with planted vegetation. This technique is usually cheaper, better for the environment and more aesthetically pleasing than artificial structures made from concrete and stone. For four years, [Agricultural Research Service](#) hydraulic engineer Doug Shields at the [National Sedimentation Laboratory](#), Oxford, Miss., and [University of Memphis](#) wetland plant physiologist Reza Pezeshki investigated willow cuttings' survival or effectiveness when planted along streambanks to control erosion. Planting willow cuttings 3 to 8 inches in diameter and 4 to 8 feet long in winter when they are dormant is an attractive option for rapidly eroding sites. The posts hold and stabilize the bank until the young trees become established. Then the willows create conditions favorable for natural establishment of native vegetation. However, in many cases, willow posts planted in streambanks have died within a year. To find ways to enhance willow survival and growth, the scientists conducted a series of field and greenhouse studies that showed that cuttings are very sensitive to moisture and soil type. They're currently developing a simple site evaluation protocol to assist streambank restoration planners in deciding where to plant willow posts. Site characteristics used in the protocol will include typical groundwater elevations and soil type. Recent greenhouse studies have shown that survival rates can be doubled by soaking cuttings for 10 days before planting. Soaked cuttings outperformed those planted immediately after they were cut, growing higher and producing more biomass and greater numbers of roots. This finding will be of great interest to all who are working to create forested riparian buffer strips, control streambank erosion and restore the nation's 3.5 million miles of rivers currently considered degraded by erosion, sedimentation and excess nutrients.

Chambers, J.C. and Miller, J.R. Editors. (2005). Great Basin Riparian Areas: Ecology, Management and Restoration. *Island Press*. Washington, D.C. 303 pages.

Established by the USDA Forest Service in 1993, the Great Basin Ecosystem Management Project for Restoring and Maintaining Sustainable Riparian Ecosystems is a large-scale research study that uses an interdisciplinary approach to examine the effects of climate change and human disturbance on riparian areas. Structured as a collaborative effort between management and research, the project focuses on understanding the geomorphic, hydrologic, and biotic processes that underlie riparian structure and function and the interrelated responses of those processes to disturbances, both natural and anthropogenic. This book summarizes the current state of knowledge about those areas and provides insights into the use of the information generated by the project for the restoration and management of riparian ecosystems. Because semi-arid ecosystems like the Great Basin are highly sensitive

to climate change, the study considered how key processes are affected by past and present climate. Great Basin Riparian Ecosystems also examined the processes over a continuum of temporal and spatial scales. Great Basin Riparian Ecosystems addresses restoration over a variety of scales and integrates work from multiple disciplines, including riparian ecology, paleoecology, geomorphology, and hydrology. While the focus is on the Great Basin, the general approach is widely applicable, as it describes a promising new strategy for developing restoration and management plans, one based on sound principles derived from attention to natural systems.

Crowder, Wayne. (1995). Collecting Willow, Poplar and Redosier (SIC) Dogwood Hardwood Cuttings for Riparian Site Plantings, *Plant Materials, Technical Note 29, U.S. Department of Agriculture Natural Resources Conservation Service*, Spokane, Washington.

Willows, poplars, cottonwoods and redosier dogwood are examples of species which may be planted direct into riparian sites as hardwood cuttings. Direct field planting on riparian sites of unrooted hardwood cuttings offers advantages over using rooted containerized plants. It minimizes to some extent the physical resources needed - - no greenhouse, lath house, plant media, plant containers, etc. The time frame between obtaining propagation material and the field planting date can be shorter. Dormant cuttings do not have to go through a "hardening off" process as live plants do. Maintaining cuttings during storage requires less personal attention than live leafy plants and dormant cuttings are less susceptible to after-planting frost than live leafy plants. Detailed information of length of cuttings, tools, time of year and storage of the cuttings is provided.

Fripp, J., Weber R., Wells, G., Romy, M., Kerry, R., Jerry, B., Hoag, C., Boyer, K. Editors/compilers. (2009, revised 2011). Stream Restoration Planning and Design Fluvial System Stabilization and Restoration Field Guide, *United States Department of Agriculture*.

A backpack field guide for assessment and planning for conceptual designs for a variety of fluvial systems stabilization and restoration purposes. General field reference and training tool to be used as adjunct at training sessions.

Gray, Donald H. and Sotir, Robbin B. (1995). Biotechnical stabilization of steepened slopes. *Prepared for Transportation Research Board 746th Annual Meeting January 22-28, 1995, Washington, D.C.*

The use of tensile inclusions makes it possible to repair slope failures or to construct steepened slopes along highway right-of-ways. Live, cut brush layers can be used in lieu of or in conjunction with synthetic fabrics or polymeric geogrids for this purpose. This approach, which is termed biotechnical stabilization or soil bioengineering, entails the use of living vegetation, primarily cut, woody plant material that is purposely arranged and imbedded in the ground to prevent surficial erosion and to arrest shallow mass movement. In the case of brush layering the live cut stems and branches provide immediate reinforcement; secondary stabilization occurs as a result of adventitious rooting along the length of buried stems. Unlike most inert reinforcements, imbedded brush layers also act as horizontal drains and wicks that favorably modify the hydrologic regime in the slope. The basic principles of biotechnical stabilization are described. Guidelines are presented for analyzing the surficial, internal, and global stability of brush layer reinforced fills. A case study is reviewed in which

live, brush layer inclusions were used to stabilize steep slopes along a roadway. A brush layer, buttress fill was used to repair an unstable cut slope along a highway in Massachusetts. Several repair alternatives were considered in this case. Scenic and environmental considerations in combination with stability analyses eventually dictated the use of a composite, drained rock and earthen brush layer fill. The rock section was placed at the bottom to intercept critical failure surfaces that passed through the toe of the slope. Biotechnical stabilization resulted in a satisfactory and cost effective solution; the treated slope has remained stable and it blends in naturally with its surroundings.

Hoag, Chris J. (2000). Harvesting, Propagating and Planting Wetland Plants, Wetland Project Information Series No. 14, July, 2000, *Wetland Plant Ecologist, Interagency Riparian/Wetland Plant Development Project*, USDA - Natural Resources Conservation Service, Plant Materials Center, Aberdeen, ID 83210

Sedges (*Carex spp.*), spikerushes (*Eleocharis spp.*), bulrushes (*Scirpus spp.*) and rushes (*Juncus spp.*) are used extensively in riparian and wetland revegetation because of their aggressive root systems. They also provide wildlife habitat for a variety of terrestrial and aquatic species. They form buffer zones that remove pollutants from surface runoff. The above ground biomass provides roughness that causes stream velocity to decrease and sedimentation to occur. The thick humus developing in those areas breaks down organic compounds and captures nutrients (Carlson 1993). Wetland plant root systems are important means of stabilizing degraded sites. Manning et al. (1989) found that Nebraska Sedge (*Carex nebrascensis* Dewey) produced 212 ft/in³ (382.3 cm/cm³) of roots in the top 16 in (41 cm) of the soil profile and Baltic Rush (*Juncus balticus* Willd) had 72 ft/in³ (134.6 cm/cm³) of roots. An upland grass like Nevada bluegrass only has 19 ft/in³ (35.3 cm/cm³) of roots. The root system is the basis for soil bioengineering. Soil bioengineering increases the strength and structure of the soil and thereby reduces streambank erosion. Most soil bioengineering applications emphasize the use of woody riparian plants. However, herbaceous wetland plants provide more fibrous root systems that in combination with the larger woody plant roots do a better job of tying the soil together (Bentrup and Hoag 1999). Wetland plants are also used for constructed wetland systems (CWS). A CWS is a wetland that is constructed in an area that has no previous history of wetland hydrology for the purpose of improving water quality. Water purification is a natural function of wetlands. The wetland plants provide suitable sites for colonizing microbial populations to establish on. The microbial populations live on the plant roots and breakdown various nutrients found in the water. The above ground biomass serve as nursery sites for periphyton that also break down various nutrients.

Hoag, J. Chris. (1995). Using dormant pole cuttings to revegetate riparian areas. *Presented at the Fifth International Rangeland Congress* (Salt Lake City, Utah, July 23-28, 1995).

Dormant un-rooted pole cuttings from woody plants of *Salix*, *Populus*, or *Cornus* genera can be planted deep enough to reach low water tables or into streambanks so flood waters won't erode them away. Large cuttings from 8 to 20 cm in diameter have much better survival than whips. The cuttings must be long enough to reach 15 cm into the water table and tall enough to be above the competing vegetation. First year's establishment success exceeds 90%. Third year's establishment success exceeds 70% during extreme drought period.

Hoag, Chris & Landis, Thomas D. (1999). Plant materials for riparian revegetation. *National Proceedings: Forest and Conservation Nursery Associations*, 33-43. Available at: <http://www.fcnanet.org/proceedings/1999/hoag.pdf>

Increased public awareness and concern have prompted new efforts in riparian revegetation using streambank bioengineering techniques. Planting in a riparian zone is very different than planting on upland sites. Riparian planting zones should be used to ensure that the vegetation is planted in the appropriate location so that the planting does not create more problems than was it was designed to treat. The types of plant materials used in riparian revegetation projects include: 1) dormant nonrooted hardwood cuttings which include 3 size classes: propagation cuttings, branched cuttings, and poles; and 2) nursery plants, including bareroot and small and large container stock. Each stock type has its specific purpose, use, and limitations. Many riparian plants are difficult to propagate so propagation protocols are being developed. Streambank bioengineering is relatively new in this country, and requires different types of plant types than nurseries are used to growing. The nursery industry needs to be proactive and pursue this new market for riparian stock by showing potential customers what they can produce and emphasizing native, locally-adapted plants for their area.

Hoag, Chris J. and Landis, Thomas D. (2001). Riparian Zone Restoration: Field Requirements and Nursery Opportunities, *Native Plants Journal* 2: (1), 30-35.

Riparian corridors can often be classified into 4 distinct zones (toe, bank, overbank, and transitional) wherein specific plants are adapted and should be planted. Nursery managers can grow a variety of species in a multitude of different stock types for planting in those zones. Bioengineering treatments are often necessary to physically stabilize streambanks before plants can be established. Four common bioengineering treatments (brush mattress, wattle, vertical bundle, poles) require specialty plant materials not generally grown in nurseries. Stooling beds of source-identified plants can yield these cuttings for an expanding bioengineering market.

Lucey, W.P and Barraclough, C.L. (2001). A User Guide to Photo point Monitoring Techniques for Riparian Areas – Field Test Edition. *Unpublished report prepared by Aqua-Tex Scientific Consulting Ltd.* Kimberley, BC for Cooperative Riparian Restoration. <http://www.google.ca/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0CCoQFjAA&url=http%3A%2F%2Fcmnmaps.ca%2Fcmn%2Ffiles%2Fmethods%2Fpdfs%2FppmAqatex.pdf&ei=L1UnU-agOZHrAH9sYDwCw&usg=AFQjCNF6sFr01dVKOr9UIPDg1lor-aV4Vw&sig2=dpsosHWeeSaAagDwZCessA&bvm=bv.62922401,d.aWM>

Photopoint Monitoring is a standardized procedure, developed largely by Dr. Fred Hall of the U.S. Forest Service, for taking precise replicable photographs of resources that require long term management (Hall, 1997). Photopoint Monitoring is both a qualitative and quantitative tool that can assist resource managers in detecting unacceptable conditions in target resources *before* severe or irreversible changes occur, and *allow time* to implement corrective actions. The technique can also be used to assess the success or failure of management decisions based on the use of clearly defined indicators and standards. The Photopoint Monitoring technique can be used as an early warning system in conjunction with

other quantitative approaches or as an independent monitoring procedure. This manual is based upon a three year trial conducted by three Environment Youth Teams, under the supervision of Aqua-Tex Scientific Consulting Ltd., followed by a 3 month intensive study of the utility of the method for the Capital Regional District (Victoria, B.C.). The purpose of that study was to determine, and field test, the range of applications of Photopoint Monitoring for riparian and ecologically sensitive areas. The Environment Youth Team tested the application of this technique for monitoring recreation and visitor impacts in local parks, fuel loads and associated fire hazard risks in the Victoria water supply; rates of riparian restoration and recovery in channelized streams, and rates of natural and artificial disturbance recovery in burned, diseased and logged landscapes.

Myhlberg, Gay and Moore, Nancy. (1998). Streambank Revegetation and Protection, a guide for Alaska. *Technical report no. 98-3, Alaska Dept. of Fish and Game, Alaska Dept. of Natural Resources, US Environmental Protection Agency.*

A field guide to assist private property owners and professional in the “how to” of streambank revegetation and protection. Chapters include info of a wide variety of revegetation techniques, revegetation zones, and plant species selection list and protection techniques.

Piper, Kevin L., Hoag, J. C., Allen, Hollis H., Durham, Gail, Fischenich, J. C. (2001). *Bioengineering as a Tool for Restoring Ecological Integrity to the Carson River*, **PDF Url:** [ADA396087](#), SEP 2001, 14 pages, **Accession Number:** ADA396087

This technical note describes a case study involving the following: (a) use of bioengineering (a combination of vegetation and engineered structures and materials) and rock structures to restore an eroded bank of the Carson River, Nevada; and (b) restoration of ecological amenities that existed prior to disturbances by man and a major flood event.

Polster, David F. (2006). Soil Bioengineering for Riparian Restoration. *Paper presented at the Canadian Land Reclamation Association 2006 Conference, Ottawa, Ontario, August 20-23, 2006, 313-322*

Soil bioengineering is the use of living plant materials to perform some engineering function. Soil bioengineering techniques can be used to treat eroding banks, excess gravel and unstable slopes and can provide a finished product that treats the problem as well as providing appropriate riparian vegetation. The natural successional process associated with development of a healthy, functioning riparian vegetation cover is the model that is used to design repair systems that encourage restoration of riparian values. By providing a living, growing system for repair of damaged sites, possibly with wood and rock, the repair can contribute to living riparian area. Soil bioengineering systems have been used to treat a variety of degraded riparian areas. Live bank protection can be used to form defensive walls of vegetation along the eroding banks of rivers, streams and ponds. Live palisades can be used to re-establish riparian forests quickly. Live gravel bar staking can be used to treat areas where excessive gravel deposits from up-slope erosion threaten downstream channel morphology. Wattle fences, live pole drains, live smiles and a variety of other techniques

can be used to treat bank instabilities. This paper presents descriptions of where soil bioengineering treatments have been used for riparian restoration. Examples are drawn from over twenty years of experience by the author.

Polster, D.F. (1991). Successional reclamation in Western Canada: New light on an old subject. Paper. *Paper presented at the Canadian Land Reclamation Association/B.C. Technical and Research Committee on Reclamation meeting*, Kamloops, B.C., June 24 - 28, 1991

Natural vegetation successional forces can be used to enhance reclamation of drastically disturbed sites. This paper presents a concept for land reclamation which is based on the use of successional processes. Identification of the factors which are precluding vegetation growth or which are limiting the establishment of additional species is the first step in the formulation of a sustainable reclamation program. Solutions for overcoming these growth limiting factors are sought from those which would occur under natural circumstances. These are then utilized in the reclamation program. Successional reclamation programs can revegetate sites which otherwise defy revegetation attempts. Examples are drawn from reclamation programs conducted by the author in western Canada.

Polster, D.F. (1999). Soil Bioengineering for Steep/Unstable Slopes and Riparian Restoration. *Paper presented at the Fourth Annual Roads, Rails and Environment Workshop*. November 2-3, 1999. Revelstoke, B.C. d.polster@telus.net

Soil bioengineering is the use of living plant materials to construct some engineered structure or to perform some engineering function. Bioengineering is used to treat steep and / or unstable slopes. Wattle fences, short retaining walls built of living cuttings, have been widely used to treat steep slopes while modified brush layers have been on ravelling slopes to control the movement of surface materials. Wet seepage areas have been treated with live pole drains while live smiles are used where flowing mud is causing slope instability. In all of these cases, the soil bioengineering structures are used to address some form of instability that is preventing natural plant establishment and growth. Riparian areas can be treated with a variety of bioengineering techniques. Live gravel bar staking provides pioneering vegetation on riparian gravel bars, encouraging sediment trapping and bar stabilization. Live bank protection provides hardened banks while enhancing riparian vegetation cover. Live shade provides immediate cover for newly constructed fish channels. This paper presents a variety of soil bioengineering techniques that can be used for the treatment of problem sites. The benefits of bioengineering, including reduced cost and maintenance are discussed. Examples are drawn from the author's experience.

WEBSITES:

Ducks Unlimited, has a variety of easy to understand information on wetlands, some information specific to NWT. <http://www.ducks.ca/your-province/territories/>

Wetlands Alberta , a great website with fact sheets and best management practices about boreal wetland types including swamp, fens, open water, marsh, restoring lost wetlands and value of wetlands. <http://www.wetlandsalberta.ca/general-public/>

Environment Yukon has wetland fact sheets with excellent info and pictures.

http://www.env.gov.yk.ca/animals-habitat/wetland_classification.php

SER Primer on Ecological Restoration, SER 2004, <https://www.ser.org/resources/resources-detail-view/ser-international-primer-on-ecological-restoration>

Division of Scenic Rivers, “A Streambank Stabilization Manual” (1986); Resources Conservation Service, Engineering Field Handbook,

http://www.gaepd.org/Files_PDF/techguide/wpb/Guidelines_Streambank_Restoration_GSW_CC_Revised_2000.pdf