STREAM SYSTEMS TECHNOLOGY CENTER

STREAM NOTES

To Aid in Securing Favorable Conditions of Water Flows

Rocky Mountain Research Station October 2009

Riparian Vegetation-Flow Response Guilds: A Tool for Determining Environmental Flows for Riparian Vegetation

by David M. Merritt, Michael L. Scott, N. LeRoy Poff, Gregor T. Auble, and David A. Lytle

Riparian vegetation is a key element of riverine ecosystems, supporting many ecological, aesthetic, and economic benefits valued by humans as well as providing terrestrial wildlife habitat structure, food resources, stabilizing properties along banks and floodplains, and energy subsidies to aquatic and terrestrial ecosystems. Flow-related variables have universally been found to be strong predictors of species distributions in riparian ecosystems. The selective pressures of particular flow regimes on riverine biota, including vegetation, have resulted in a range of morphological, life-history, and phenological adaptations unique to riparian taxa. Assemblages of species exhibit traits that enable them to disperse, survive, and reproduce in response to specific streamflow components. Thus, there is often a strong interconnection between a river's natural flow regime and the traits of its riparian species.

Altered flow regimes may cause shifts in plant population structure, plant growth and productivity, plant community composition, changes in riparian plant species richness and diversity, and loss of riparian forests. Infrastructural developments that alter flow regimes have significantly changed river processes and aquatic and riparian ecosystems worldwide, but at the same time offer opportunities for restoration of these ecosystems through environmental flow management.

Understanding specific adaptations of organisms to components of the flow regime is leading to the development of a range of tools for determining the flow necessary to sustain the physical and biological diversity of riverine ecosystems. Whereas species- and cover-specific models have been developed for riparian vegetation at specific sites, a more general framework is necessary. Merritt and others (2009) provide an overview of theory, methods, and models for quantitatively linking individual plants, plant populations, and riparian plant communities to specific streamflow attributes to inform management of river flows and to

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CORRESPONDENCE:
E-Mail: rmrs_stream@fs.fed.us
Phone: (970) 295-5983
FAX: (970) 295-5988

Website:
http://www.stream.fs.fed.us

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quantify flow regimes necessary to support desired riparian vegetation attributes. In this paper, we summarize the concept of *riparian vegetation-flow response guilds* that was introduced by Merritt et al. (2009). *Riparian vegetation-flow response guilds* are groups of species that respond in similar ways to similar attributes of flow, and are proposed to aid in the development of a more general framework for managing rivers to support riparian function.

Because water is the principal limiting resource for plants, their fitness, vulnerability to pathogens and herbivores, species richness, productivity, biomass, competitive ability, population structure, and community composition are supported by and respond directly to flow-related processes. Understanding these linkages and quantifying the relationships statistically could contribute to the defensibility of flow prescriptions. A range of models have been developed for linking attributes of riparian vegetation to characteristics of streamflow regime ranging from simple statistical relationships between plant and flow attributes to more complex structured stochastic population and dynamic simulation models.

Characterizing Flow Regime

Ecologically relevant components of streamflow include the flow magnitude, flow frequency, flow duration, timing of particular flow components, rate of flow change, interannual variability, and sequencing of flows. Classifications of flow regimes have identified distinct patterns of streamflow at regional, continental, and global scales. Although a core set of hydrologic indicators has been identified for aquatic taxa, this has not yet been achieved for riparian vegetation. Understanding the characteristic flow regime of a site can aid in determining which flow attributes might have been (or will be) altered by current or future development and which attributes might be tightly linked to an attribute of riparian vegetation that might be of conservation or management concern.

In too many cases, flow management prescriptions only consider a single attribute of flow (e.g., minimum flow). Such narrow consideration of flow needs of riparian vegetation may serve to maintain extant species for some isolated period of time (i.e., life support), but neglect many other important aspects of flow that are likely necessary for riparian management and riparian conservation. Timing of peak and low flow, rate of flow change, flood frequency and magnitude, flow duration, flow variability, and myriad of other potentially biologically important flow attributes must be considered in developing flow-biotic response relationships.

Flow variables of interest may be readily calculated using available streamflow data from the U.S. Geological Survey (Olden and Poff 2003; http://waterdata.usgs.gov/usa/nwis/sw), modeled flow from regional flow relationships (Turnipseed et al. 2006; http://water.usgs.gov/software/NSS/), or other flow estimation techniques for ungaged streams. Streamflow data may be summarized using software such as Indicators of Hydrologic Alteration (IHA; Richter et al. 1996; http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html) or the U.S. Geological Survey. Hydroecological Integrity Assessment Process (HIP; http://www.fort.usgs.gov/Resources/Research Briefs/HIP.asp). Redundancy and the number of potential biologically relevant hydrological variables may be reduced to a subset of key drivers for use in vegetation models using the methods outlined in Olden and Poff (2003).

Linking Riparian Vegetation to Streamflow

Collectively, the flora in a riparian area may contain a diverse assemblage of species with numerous combinations of tolerances and requirements (fig. 1). In modeling riparian vegetation-streamflow relations the choice of measurement at the level of the individual, population, community, or cover type (or some combination), will largely depend upon the vegetation attributes that are deemed important along with established goals for maintenance and restoration of riparian vegetation. Although altered hydrologic attributes result in individualistic responses by species in accordance with their life-history attributes, collective responses may be revealed as changes in community attributes, plant communities, and plant cover types.

Fitting a distribution or function to presence-absence or abundance data of a species along a flow-related environmental gradient may provide insight into the breadth of the species' realized niche and indicate ecological amplitude and its environmental optima along environmental gradients. Classifying communities into cover types can be achieved by

Figure 1. Photographs illustrating the various types of riparian vegetation that occur along streams. Upper left photo: A stable, perennial fluvial marsh along the regulated upper Green River, UT. Upper right photo: A sycamore-hackberry disturbance-adapted riparian forest along the unregulated upper Gila River, NM. Lower left photo: Perennial wetland species along the regulated North Fork Cache La Poudre River, CO. Lower right photo: A remnant cottonwood forest along the regulated upper Green River, UT.

examining dominant woody species, growth forms (e.g., woody versus herbaceous cover), or using ordination and clustering techniques. These community or cover types may then be modeled to relate spatial distribution or probability of occurrence of cover types to attributes of the flow regime and/or groundwater levels.

Other attributes used to characterize vegetation include biomass, vegetation volume, growth rates, and stand physical structure. These attributes can be regressed against flow variables, and the relationships can be used to estimate stand attributes in response to various flow-alteration scenarios. One advantage of these simple approaches is that a full range of responses is modeled, enabling an evaluation of trade-offs between flow alteration and measurable riparian conditions. A disadvantage of these techniques is that the relations are often river or site-specific, limiting transferability of relationships to other rivers even in the same hydroclimatic region. Considering vegetation response to flow alteration as a whole obviates many of the limitations of generalizing the response of individual species.

Functional Groups

To facilitate generalization across systems, grouping riparian plant species by some shared functional attribute can be a practical way to generalize and transfer patterns from one system to the next. Stream ecologists have developed functional classifications of aquatic species into groups with similar biological and ecological traits that are expected to respond consistently along specific environmental gradients. Although different species respond to different components of the streamflow regime, groups of riparian plant species that respond in similar ways to specific attributes of the streamflow regime or fluvial processes can be identified.

Because plant traits are a product of natural selection, trait convergence may occur in plant communities experiencing similar selective pressures. When selective pressures, such as flow and fluvial disturbance regimes are similar, convergence of plant traits should occur even across biogeographic boundaries and phylogenies. The reproductive phenology of pioneer riparian tree species in relation to seasonal floods around the world, root morphologies for water acquisition, and

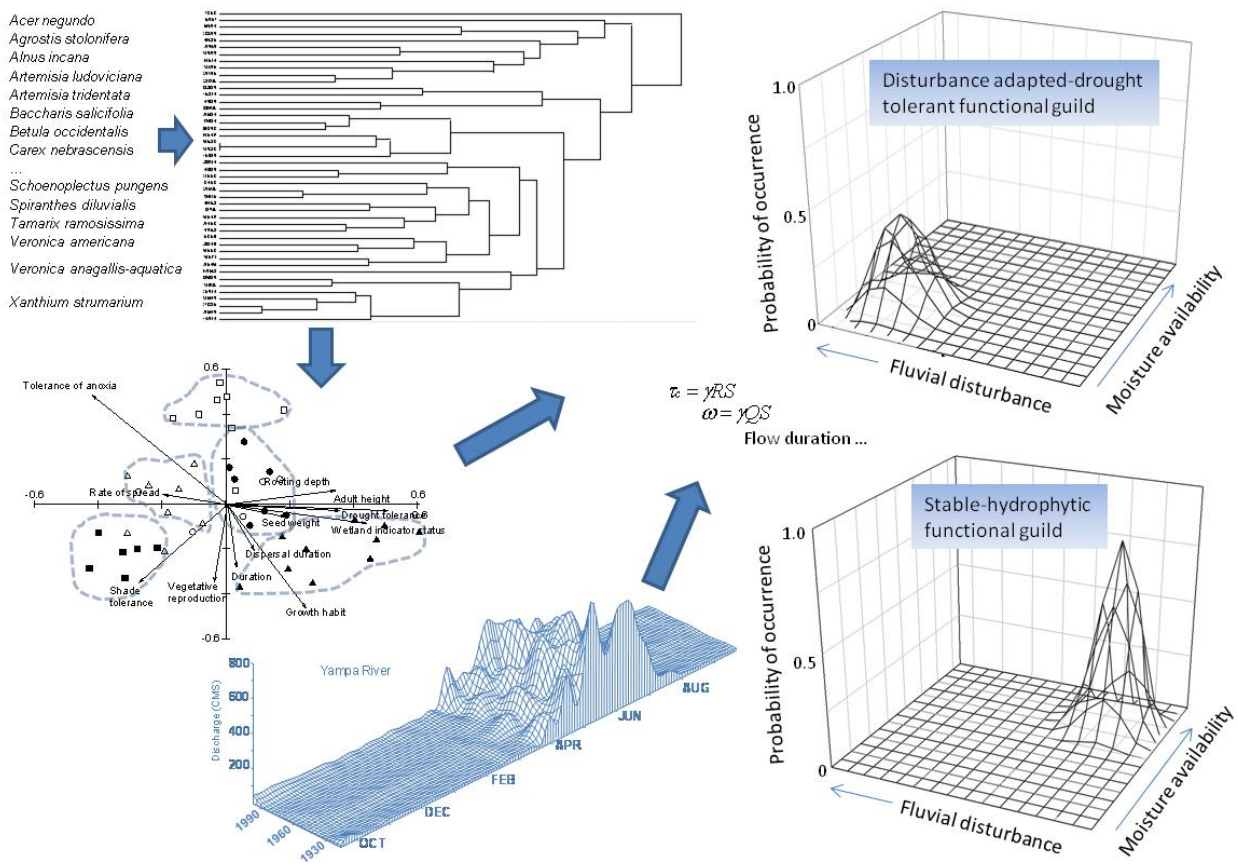

Figure 2. The process of using riparian vegetation-flow response guilds. First, each species in the riparian flora for a region is classified into functional groupings based upon their physiological and morphological attributes (in this example, agglomerative clustering and principal coordinates analysis were used). Then, the distributions of these functional guilds are modeled as a function of fluvial disturbance and moisture availability. Measures of fluvial disturbance could include critical shear stress, stream power, exposure, or some combination. Measures of moisture availability could include flow duration, flow depth, or some other measure or index of moisture availability. Models of current distributions of functional guilds along these environmental gradients could then be used to predict shifts in functional guilds in response to streamflow alterations because of land-management activities or climate change.

sexual versus vegetative reproductive strategies, provide some examples of such trait convergence. Riparian cottonwood (*Populus deltoides* in western North America and river red gum (*Eucalyptus camaldulensis)* and swamp paperbark (*Melaleuca rhaphiophylla)* in Australia release short-lived seeds for a short period of time in synchrony with the recession of floods. The capacity to produce deep taproots exemplifies the convergence of root morphologic traits in phreatophytes in the northern hemisphere (e.g., many species of the Salicaceae family such as velvet mesquite, *Prosopis velutina*) and southern hemisphere (e.g., red iron bark, *Eucalyptus sideroxylon*).

The ecological guild or functional group concept provides a framework for identifying species with shared responses to environmental variation. Some authors have distinguished between structural guilds (groups of species that use similar resources) versus guilds that function as a 'super species' or groups of species that collectively respond to environmental variation in a similar manner. We adopt the latter concept of guilds in developing our framework for riparian vegetation.

Selecting the meaningful plant traits for categorizing species into guilds or functional groups requires a solid mechanistic understanding of the relationships between traits and environmental gradients. Such specific trait linkages, statistical correlations among traits, and evolutionary lability of traits provide a basis for predicting responses of communities to changes in physical processes (fig. 2).

The Development of Riparian Vegetation-Flow Response Guilds

To overcome the shortcomings and limitations of the site-specific nature of individual, population, and community based models, we propose a general framework for modeling riparian vegetation-streamflow relations. The foundation of this framework is derived from the rich and extensive plant ecology literature in which functional approaches to grouping plants is well-developed. Plant physiological and morphological information may be obtained from the literature, empirical data, and through online databases such as the USDA, Natural Resources Conservation Service Plants database (http://plants.usda.gov/).

We define groups of riparian plant species that respond in similar ways to quantifiable flow attributes as *riparian vegetation-flow response guilds* or simply *riparian response guilds*. We categorize the riparian response guilds into five categories: life history, reproductive strategy, morphology, fluvial disturbance, and water balance. Non-phylogenetic associations of plant communities have been used to predict ecosystem response to disturbance, water depth and exposure, resource gradients, and groundwater decline. Such functional classifications provide a broader framework for predicting riparian vegetation responses to changes in environmental variables than do analyses of individual plant species response curves, communities, and cover types along gradients (as outlined above). We propose a riparian response guild framework that considers key non-phylogenetic attributes of riparian vegetation.

Life-history guilds

The life-history guild includes life span of the individual, a key determinant of response time to a change in hydrologic conditions. The life span of species groups has relevance to the response of such groups to changes in the timing and duration of disturbance as well as the length of time between such disturbances. For example, annual or other short-lived plants may be present or absent as a function of seasonal flow regime whereas long-lived riparian forest species may persist for a century or more after the flow-related processes necessary for forest stand formation have ceased. Life span (as opposed to classification as annual or perennial) is a quantitative measure of typical length of life. Different life-history guilds may be used to develop an understanding of the sequence and duration of responses that should be anticipated following a change in flow regime.

Reproductive-strategy guilds

Reproductive strategies of plants include: 1) phenology (timing of seed release), 2) type of regeneration (sexual versus vegetative), 3) reproductive cycle of the plant (annual, biennial, short and long-lived perennial), 4) seed longevity or propensity for dormancy, and 5) length of time to first reproduction. Because of the typical temporal variability of the flow regime and high resource heterogeneity in riparian areas, numerous reproductive strategies may co-exist in a given system. For example, phenological adaptations include delayed flowering during submergence and dispersal timed to increase the likelihood of suitable habitat availability during dispersal. Reproductive specialists (responsive to attributes of flow regime) are expected to be sensitive to changes in the timing of various flow components and rates of change in flow. Rivers or river reaches that have more stable flows and less extreme flooding (higher elevation streams, spring-fed streams, swamps, regulated rivers) tend to be dominated by perennial species with vegetative reproduction strategies.

Morphology guilds

Canopy height, canopy volume, root depth, and root architecture are among the structural traits of plants responsive to and reflective of hydrologic variability. When changes in flow permanence, total annual discharge, and depth to groundwater occur, communities may shift in predictable ways according to traits associated with water acquisition (e.g., root morphology). Shifts from tall forest species to shorter shrublands or meadows may reflect a directional or threshold response to water depletion. The presence of woody and herbaceous vegetation may also be tightly linked to timing and sequencing of floods and duration of inundation. Linkages between physiognomy of the vegetation and flow regime could guide managers in structuring flows to provide specific native habitat types such as multi-layered forest canopies for neotropical birds or moist meadows for obligate riparian mammals.

Fluvial-disturbance guilds

Several plant trait "syndromes" exist in river

ecosystems around the world as co-evolved adaptations to fluvial disturbances. These syndromes are likely to vary as a function of natural patterns of disturbance in these systems (magnitude, frequency of flooding). Furrowed bark, flexible stems, and the ability to re-sprout after stems are damaged are all traits that are common to groups of disturbance-adapted woody species living along rivers throughout the world. Several genera share these traits within families (e.g., Salicaceae). These adaptations are readily identified for individual species, and the relative importance of such guilds in the riparian community should exhibit a strong relationship to characteristics of the flow regime.

The ability to root adventitiously from stems is an adaptation both to burial of stems by sediment and to acquisition of oxygenated water in inundated areas. Whereas terrestrial plants almost never experience burial by sediment, burial is a frequent occurrence along free-flowing rivers. Plants may possess tubers, rhizomes, and/or pointed shoots to facilitate upward penetration of sediment following burial. Adventitious rooting from stems enables a plant to acquire nutrients, water, and oxygen from the accumulated sediment around its stem following burial. Such traits should be more prevalent in riparian areas with frequent fluvial disturbances and become less prevalent in systems that have naturally low or altered levels of disturbance. Altered disturbance patterns are likely to have a more severe effect on seedlings and earlier growth stages for most species. However, if seeds are available following disturbance, fresh deposits of alluvium provide centers or nodes of colonization.

The proportion of the riparian community with adaptations to disturbance should be higher in systems with high frequency and magnitude of disturbance. Shifts in this guild will occur in accordance with magnitude and direction of the disturbance change at a rate determined to some degree by the life-history traits of those species included in the guild.

Water-balance guilds

In hydrologically variable riparian environments, plant species often have adaptations to conditions associated with periods of flooding as well as periods of drought. Species vary greatly in their ability to regulate their water pressure potential (through stomatal closure or other leaf morphologic traits). Many species of riparian plants, particularly in arid regions, require access to a permanent or seasonal water supply and are intolerant of low internal water pressure potentials. Other species may have an affinity for fine-textured substrates with high water-holding capacity, or may be able to use water at low soil-water pressure potentials. Some riparian species can use different water sources over the course of the season, with various proportions of transpired water coming from groundwater versus soil water depending on relative availability. Such species may be better adapted to extended periods of low flow caused by drought, groundwater pumping, and water extraction. Plants along streams where water has been diverted may exhibit morphologic responses to enhance water-use efficiency such as reduced leaf size and increased leaf thickness.

Generally, the 'water balance' riparian response guild spans a trait gradient from anoxic conditions associated with prolonged flooding to periodic soil desiccation. At intermediate positions along soil hydrologic gradients lie groups of riparian species with traits selected for hydrologically variable conditions and possess adaptations to conditions of both moisture excess and scarcity or are transient, occurring only when favorable conditions exist.

Summary

As with individual species, plant distributions can be fitted to entire guilds along various gradients to place predictions of plant trait occurrences in the context of hydrologic characteristics. Once such response curves have been constructed and calibrated for specific stream types within hydroclimatic regions, the response of guilds to a range of hydrologic alterations may be predicted and used to inform management decisions. By using standard hydrologic components and plant community attributes applicable to all streams, the riparian response guild framework facilitates prediction of riparian plant community attributes and likely responses to flow regime alteration and is transferable and may be generalized across catchments and regions (fig. 2).

Discussion and Conclusions

We may enhance our ability to make predictions across a broader range of systems by using the riparian response guilds framework. The next steps

toward implementing such a framework will involve quantifying the attributes of plant species into regional lists and determining the guilds to which they belong. Probabilistically modeling the distributions of riparian response guilds along quantified gradients of water availability (flow duration or inundation duration) and fluvial disturbance (frequency, magnitude, duration) will enable us to assess the efficacy and refine the riparian response guilds framework, and begin to apply it to flow management. In riverine environments, predictors for fitting response surfaces to functional groups might include factors such as flow duration, flood frequency and magnitude, stream power, shear stress, critical shear stress, or other flow and fluvial mediated variables.

This approach has the potential to overcome many of the shortcomings of conventional modeling approaches. As distributions are most often developed empirically at sites, they only include plant species currently at the sites (excluding the consideration of other species which may have been extirpated or those suited to current or future site conditions) and may be difficult to apply beyond the range of site-specific calibration, as relationships between streamflow and the response variables may vary by site. Modeling multiple species at a site along with some model component that connects them may provide a probabilistic view of community dynamics but may be difficult to summarize as clear and explicit management prescriptions. Application of riparian response guilds will enable the scientist and manager to talk in general, but practical terms about the probable changes in vegetation attributes (e.g., guild shifts).

A central aim of plant community ecology is to predict the composition of communities in response to changing environmental conditions (fig. 2). This often requires balancing the details of specific sites and plant species with general plant ecological theory in such a way that the necessary information is effectively conveyed to land managers and translated into land-management strategies. Statistically linking riparian vegetation flow response guilds to hydrologic gradients, regionally calibrating these relationships, and using them to guide river flow management provides an important development toward such a framework. This flow management framework provides a level of generalization that can be used to establish flow standards on individual streams and catchments and to facilitate transferability of flow standards to related streams in a river classification scheme. This approach also helps obviate the need to prescribe river and site-specific recommendations of flow by allowing development of some general guidelines for multiple streams within particular streamflow classes. Our riparian vegetation flow-response guilds framework provides a sound riparian vegetation component to a holistic approach to river and environmental flow management.

Additional Information

For a more in-depth discussion on this topic along with a comprehensive list of references, please refer to the following publication: Merritt, D.M., Scott, M.L., Poff, N.L., Auble, G.T., Lytle, D.A. 2009. Theory, methods, and tools for determining environmental flows for riparian vegetation: riparian vegetation-flow response guilds. Freshwater Biology. Doi:10.111/j.1365-2427.2009.02206.x. Copies of this article are available online from the STREAM website: http://www.stream.fs.fed.us/publications/documentsStream.html.

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David M. Merritt is a riparian ecologist; USDA Forest Service, Stream Systems Technology Center; Fort Collins, CO 80526; 970-295-5987; dmmerritt@fs.fed.us.
Michael L. Scott is a research ecologist; U.S. Geological Survey, Fort Collins Science Center; Fort Collins, CO 80526; 970-226-9475; scottm@usgs.gov.
N. LeRoy Poff is a professor; Colorado State University, Dept. of Biology, Fort Collins, CO 80523; 970-491-2079; poff@lamar.colostate.edu.
Gregor T. Auble is a research ecologist; U.S. Geological Survey, Fort Collins Science Center; Fort Collins, CO 80526; 970-226-9230; aubleg@usgs.gov.
David A. Lytle is an aquatic ecologist, Oregon State University, Dept. of Zoology, Corvallis, Oregon 97331, (541) 737-1068, david.lytle@science.oregonstate.edu.

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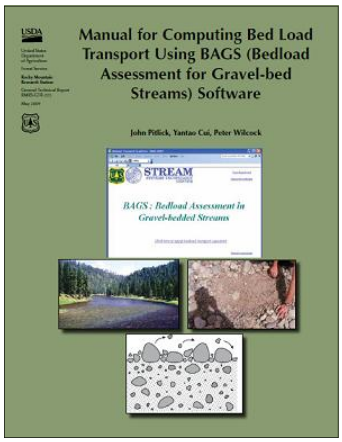
BAGS (Bedload Assessment for Gravel-bed Streams) Software Update



The BAGS software that was originally released in July 2009 was recently updated in October 2009 to accommodate a recent automatic update of Excel by Microsoft. This Excel update by Microsoft made certain functions of Visual Basic Applications for some programs, such as BAGS, inoperable. The most recent version of the BAGS program along with the BAGS user's manual can be downloaded from the STREAM website: http://www.stream.fs.fed.us/publications/software.html. Users are encouraged to periodically check the STREAM website for the latest updates to the BAGS software as it may be updated as features and modeling capabilities are added to the program.

BAGS is supported by, and limited technical support is available from, the Streams Systems Technology Center, Fort Collins, CO. The preferred method of contact for obtaining support is to send an e-mail to rmrs_stream@fs.fed.us requesting "BAGS Support" in the subject line.

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