

Watershed/River Channel Linkages: the Upper Rio Grande Basin and the Middle Rio Grande Bosque

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Abstract—There continues to be a great deal of interest and discussion surrounding the demands of water management and allocation and the relationship to ecological integrity of the Rio Grande riparian ecosystem. Current river management too often fails to consider the importance of natural variability of flows. What is consistently overlooked is the relationship of a stream course to its forming watershed. The standard practice of managing for one or more of a few important or imperiled species by defining how little water can be left in the river is not adequate based upon new scientific understanding. Adaptive management approaches can be used to manage for whole river ecosystems concurrent with providing societal and cultural demands on these natural systems.

The Middle Rio Grande (MRG) riparian forest, or “bosque”, represents the largest cottonwood gallery riparian forest in the southwestern United States. This reach of the Rio Grande extends from Cochiti dam downstream 260 km to San Marcial, New Mexico. It constitutes 8 percent of the river’s total length and 34 percent of its length in New Mexico. The current bosque is a relict of past management activities and is notably different than its historic character. The physical and biological characteristics of southwestern riparian systems are complex. Natural processes in southwestern riparian systems and the ecological adaptations of vegetation affected by flood induced disturbance are fundamental aspects to be considered.

What is consistently overlooked is the relationship of a stream course to its forming watershed. Once understood, this relationship facilitates the ability to recognize the character and condition of the riparian reach under study both from a temporal and spatial perspective. The annual natural variability of flows from a watershed and infrequent episodic high flows (floods) are important aspects in understanding the expected and necessary natural variability of flows. Flood events reset the condition of these systems. Too often the casual observer interprets the effects of reforming floods as “destructive.” While understandable, this conclusion may be hasty and is often incorrect.

A complex set of factors are involved in the development and maintenance of these landscapes. The variability in

hydrology and river morphology of these systems precludes use of random sampling in order to accurately characterize these dynamic habitats. As a result of man’s activity in most southwestern watersheds today, the changes to the hydrology and the loss of active floodplain combined with changes in sediment supply and availability in the river system have all contributed to a loss of biological integrity.

The benefits of inter-annual flooding is a potential resource that was effectively used by the original floodplain system. Development within the floodplain, accompanied by diking, alterations of the natural hydrograph, and channelizing, are the results of the perception that flooding must be controlled.

Gregory and others (1991) describe riparian zones, the interfaces between terrestrial and aquatic ecosystems, as a mosaic of land forms, communities, and environments within the larger landscape. These were perhaps the first authors to present an ecosystem perspective of riparian zones that focuses on the ecological linkages between terrestrial and aquatic ecosystems within the context of fluvial land forms and the geomorphic processes that create them. They observed “that geomorphic processes create a mosaic of stream channels and floodplain within the valley floor. Geomorphic characteristics and other processes including stochastic disturbance both upland and fluvial in origin affect riparian zones, determining the spatial pattern and successional development of riparian vegetation.”

In general, the factors affecting the development of southwestern riparian habitat are as follows:

1. Creation of a favorable seedbed;
2. Progression of tree stands from nursery bars to senescent individuals as they continually modify their own habitat;
3. Light to moderate flooding favors the establishment and development through deposition of nutrient-rich sediments and increased soil moisture; and
4. Successful seeding cannot be expected on an annual basis since it depends upon a “proper sequence of flooding,” that is, no flooding large enough to be catastrophic until stands are well developed.

Stromberg (1993) found that flow volume and the related attributes of water-table recharge and floodplain soil wetting are primary factors regulating riparian vegetation abundance. For example, many riparian tree species in the arid southwest are evolutionarily adapted to germinate after high spring flows, which occur as a result of snowmelt and run-off from winter rains, whereas others germinate after high summer flows, which are driven by monsoonal summer rains (Stromberg and others 1991). Many arid land streams are water limited on an annual or seasonal basis

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because discharge has such a high degree of temporal flux (Graf 1982; Poff and Ward 1989). The combination of high peak flows in conjunction with low mean annual flows may serve to reduce the vegetation of small streams (Stromberg and Patten 1990). Flooding plays an important role in regulating accumulations of woody debris and nutrient dynamics in southwestern riparian ecosystems. In arid landscapes where precipitation is limited, moisture made available through fluvial interactions may play an essential role in facilitating the release of nutrients contained within wood and leaf litter on the forest floor (Ellis and others 1995). Flood flows in some systems play a major part in 'shaping' valley floors and in physically delimiting floodplain from adjacent uplands, by variously scouring or depositing alluvial sediment (Gregory and others 1991; Hill and others 1991). Larger streams thus might be expected to have a greater extent of sites suitable for establishing riparian vegetation.

Flood flows of a given magnitude, frequency, and seasonal timing are also important because of their roles in influencing species diversity patterns and in creating opportunities for riparian vegetation recruitment.

Beyond the physical characteristics of watersheds and their resultant channels, supplies of minerals and detritus (nutrients) is consideration of the supply and availability of elements to the stream biota is important. The impact of short-term events like storms on the elemental dynamics in streams should be assessed and compared with other controls. These factors are essential for rates of primary productivity and decomposition in streams. The major controls on element supply to a stream include watershed geology and hydrology, soil processes, land-use practices, landscape vegetation, and atmospheric loading. These watershed- or landscape-level process define the overall supply of elements to a stream. (J.L.Meyer and others 1988).

Landscape Scale Ecosystem Management

The study of spatial and temporal patterns across landscapes is central to formulating ecosystem management principles. The hierarchical structure of ecological systems allow the characterization of ecosystems and the identification of patterns and processes at different scales. Ecosystem composition, structure, and function determine diversity patterns across a range of spatial-temporal scales. There is no single correct scale at which to study and manage ecological patterns, processes, and diversity. The ecological hierarchy of interest is determined by the purpose of each project. Hierarchical monitoring schemes must be formulated that consider all scales of ecological organization. Patterns of natural variability across a range of scales must be defined if ecosystems are to be sustained at all relevant scales. Landscapes are heterogeneous mosaics of patches (Forman and Godron 1986; Urban and others 1987).

Programmatic riparian restoration is further complicated since rainfall and streamflow do not annually coincide with seed drop from many pioneer riparian tree species. Many arid land streams are water-limited on an annual or seasonal basis because discharge has such a high degree of temporal flux (Graf 1982; Poff and Ward 1989). The

combination of re-organizing high peak flows in conjunction with low mean annual flows may serve to reduce the vegetative cover of (small) streams (Stromberg 1993).

An alternative hypothesis is that geomorphological features rather than hydrological features regulate riparian abundance within a watershed. As stream flow increases, so too does the magnitude of the low frequency hydrological events. Flood flows in some systems play a major part in shaping valley floors and in physically delimiting floodplains from adjacent uplands, by variously scouring or depositing alluvial sediment (Gregory and others 1991; Hill and others 1991). Larger streams thus might be expected to have a greater aerial extent of sites suitable for the establishment of riparian vegetation.

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Linkages Between Watershed Condition and Flows

There is an obvious direct relationship between watersheds and the water courses which result. As conditions within a watershed are altered either by natural biotic (for example insect mortality to large stands of forested trees) or abiotic events (such as fire, landslides) or by anthropogenic activities, development, road construction, timber harvesting or livestock grazing as examples, the associated watercourses adjust to the changes in discharge, seasonality, or landform. There is little argument that anthropogenic activities in riparian systems and their associated watersheds have a marked negative impact upon these natural systems. The magnitude and frequency of these activities as well as the timing of the particular action have a significant role in the exhibited resulting effects. To a large extent mitigation and management can reduce these negative impacts to tolerable levels and riparian system functions may remain within the limits of acceptable natural variation.

A properly functioning riparian stream system (including the associated watershed) can be referred to as being in dynamic equilibrium. This can also be thought of as being within the acceptable limits of natural variation for that stream system. In all discussions regarding river morphology, it is important to recognize the differences within spatial and temporal scales. To describe a river system as being in a state of dynamic equilibrium (or energy balance) does not mean that it is static. To the contrary, this "equilibrium results from a collection of processes that are by definition predicated on change" through time (Crawford and others 1993). For example, even during periods when the entire river system is considered to be in a state of dynamic equilibrium, changes constantly occur in channel segments or reaches as small as the outside bend of a meander, or as large as many river kilometers upstream, and downstream from a tributary inflow (Whitney 1996). Likewise, this state of dynamic equilibrium, can accommodate climatic deviations from the norm distinguished between natural and human-caused perturbations. The geomorphic process triggered in response to a change in

magnitude or duration of a variable, regardless of the cause, will be the same (Leopold and others 1964). The river constantly adjusts, always trying to establish a new equilibrium between its discharge and sediment load (Bullard and Wells 1992).

Often times when specialists go to the river to assess what needs to be done to restore the site, the focus remains on the condition of the channel and aquatic habitat alone without consideration of upstream factors responsible for the current condition of the reach being addressed.

Beyond that, many have difficulty imagining, let alone measuring, highly variable conditions over complex large watersheds. Because the effects of changes within watersheds are multifaceted and difficult to predict, planning and implementation of successful active restoration projects must include monitoring key watershed processes. Aspects to be monitored include geomorphic conditions, relative topographic relief, soils, climate, permeability, vegetative ground cover, water chemistry, nutrient production, movement and cycling, flow characteristics, sediment delivery and transport regimes, riparian conditions, and aquatic organisms.

Natural Variability in River Flows

Natural river systems can and should be allowed to repair and maintain themselves (Poff and others 1997). Restoring riparian ecosystems must involve restoring or at least mimicking their natural flow regime. Realistically this will involve a mix of human-aided and natural recovery methods. Management of a healthy river is more than creating an artificial constant low flow or tolerating the occasional "100-year flood" be it natural or orchestrated by man. There are five often overlooked components of a river's flow regime: magnitude, frequency, duration, timing and rate of change. Flow modification has cascading effects on the ecological integrity of rivers. The importance of natural variability to aquatic and riparian ecosystems demonstrate that unfettered rivers have multiple benefits for nature and for human society. Changes to the natural flow regime constitute one particularly important and underappreciated cause of declining health of rivers. Natural variability characterizes all ecosystems. Variability in river flow is a prime example of such natural variability. Each river has a natural flow regime, which can be altered by a variety of human actions including dams, diversions and diverse ways in which hydrologic pathways are altered. Natural variability in river flow creates a wide range of habitat types and ecosystem processes that maintain the natural biological diversity of aquatic and riparian (stream side) species. A major consequence of this natural variability is that all species experience favorable conditions at some time, preventing any one species from dominating.

Alterations of the natural flow regime result in numerous physical, chemical and biological changes to river ecosystems and may traverse many political boundaries. (Tyus 1990).

Changes in flow shape and duration can have direct and indirect effects. Direct effects of flow alterations are certainly important if migrations are blocked, fish are trapped

in de-watered sections, or reproduction is disrupted. Insidious effects may be far more detrimental, and include alterations and loss of stream habitat, introduction of competing non-native fishes, degradation of water quality, and other effects. For example with a reduction in steam flooding change nutrient cycles and disrupt food webs which have serious ecosystem consequences.

Examples include not just fish migrations but also recruitment of riparian trees, maintenance of sandbars in river channels, and sustenance of wetland habitat dependent upon flood plain inundation. Our understanding of the linkages between natural flow regime and the ecological functioning of rivers provides a powerful scientific basis for river management and restoration.

Water resource developments and operations may affect stream resources both beneficially and adversely (Tyus 1990). Return flows from irrigation projects maybe warmer, sediment laden, and contaminated with chemicals, including biocides and fertilizers. Conversely return flows into river channels during droughts can provide some beneficial effects. Planned flows can mitigate and potentially enhance natural components of riverine systems.

Instream flows are a public trust, and stream ecosystems must be protected as irreplaceable resources. Letting a river do its own thing—come drought or high water—is more complicated. Most western states have recognized in-stream flow of some form. This may be by design or by default depending upon the river system being examined. In fact, all 11 western states have some degree of in stream flow mechanisms. Despite the lack of an existing instream flow designation in New Mexico at this time, the State Attorney General and The Office of the State Engineer in April of 1998 announced that in-stream flow does have value for fish, wildlife, and ecological purposes. With the caveat that this would only be possible if an existing water right was employed for such purposes, it still is a positive move toward a fuller appreciation for free flowing water in riverine systems in New Mexico.

Natural Flood Flow Disturbance

The variability of watershed condition, channel morphology, flow regimes, differences in flood generated disturbances, and the intensity of those perturbations are all factors which have a direct role in the location, establishment, and relative maturity of a particular stand of riparian broadleaf trees.

Hypotheses on the coexistence of plant species (Connell 1979), niche differentiation (Grubb 1977), and resource partitioning (Denslow 1980) in plant communities have relied heavily on the requirement for some form of disturbance during the life cycles of many plant species. In general, disturbance reduces the dominance of a site by established individuals and creates openings for colonization and growth by new individuals. Establishment of woody plants species associated with riverine systems in the arid southwest are no exception to these general principles.

Large volume floods are the primary disturbance event affecting southwestern riparian systems (Stromberg and others 1991). Typically, these large flood events occur on approximately a 10 year recurrence frequency (House 1993).

In uncontrolled systems, estimating flood frequency is complicated because climate affects the magnitude and frequency of storms that cause floods (Webb and Betancourt 1992). The magnitude of these recurring flood events is dependent upon several features including storm event, watershed condition (LaFayette and DeBano 1990), soil saturation including snowmelt potential (House 1993), channel morphology, and condition and associated riparian vegetation cover (Stromberg and others 1991).

Desert streams draining large watersheds provide an excellent opportunity to test successional concepts in running waters (Fisher 1986). The importance of hydrology to arid land riparian vegetation has long been recognized. Zimmerman (1969) stated that: "Drainage area, geology, and flow regimen are probably the three most important controls in the distribution of valley-floor vegetation" in the arid southwest. Unfortunately, all too often researchers and field personnel of various land management agencies have focused too intently upon the FORM of a given riparian area and not given substantive consideration to the FUNCTION of the area evaluated (LaFayette and DeBano 1990).

In a generalized sense, little of what we know about lotic systems has come from work done on southwestern "desert" streams. Fisher and Minckley (1978) found that the generalized xero-riparian stream is "hydrologically flashy," responding rapidly to summer storm events with "wall of water" flash floods up to 50 cubic meters per second. The product of this and other general features of desert streams yields a stream where the main channel is wide, shaped largely by rare flooding events.

A principle effect of natural disturbance is to alter the availability of resources for plant growth. Pickett and White (1985) suggested that there are at least two mechanisms by which disturbances can temporarily increase the availability of light, water, and soil nutrients. The first is simply the reduction in rates of uptake or use of resources due to the loss of biomass. The second mechanism is the decomposition and mineralization of nutrients held in organic matter (Bormann and Likens 1979). Large scale disturbance as a result of out-of-bank or scouring flood flows produces a temporary increase in some of the resources necessary for the establishment of new stands of canopy species and understory plants in riparian systems in the arid southwest. In addition, there is also a net gain of energy into these systems through the movement of nutrients into the riparian zone from adjacent uplands (Meyer and others 1988).

There is a positive relationship between disturbance size or intensity and the availability of resources for plant growth. In addition to the expected benefits of reduced biomass per unit area, the degree of reduction in rates of transpiration and interception of water, and the uptake of nutrients, there is typically a high degree of nutrient movement associated with flows of all magnitudes in riparian zones.

An important feature of any increase in resource availability produced by a disturbance is its transient nature. As biomass is re-established at a site, the relative availability of resources for future colonists will, in general, decline. Flood disturbance produces a distinct and marked transient pulse of nutrients and organic matter into the riverine system. This represents a distinctly different pattern to which plant species can respond than that of an intact community which has equilibrated with the rate of supply of

resources (Tilman 1982). In communities where there is rapid regrowth of vegetation following a disturbance, the availability of resources for colonization should reach a peak soon after a disturbance. Consequently, the first plants that become established after a disturbance should benefit from greater availability of resources than plants that become established later. Seedlings of many species of woody plants often establish rapidly. Rapid germination following a disturbance flow should be particularly critical for species of woody plants that are intolerant of shade.

Patterns of seed production and dispersal vary widely among woody plants. One of the most conspicuous patterns of seed production and dispersal is the copious production of light, wind dispersed seed in the spring coinciding with typical spring runoff peaks. This reproductive strategy is generally correlated with the ability to respond to large disturbances (Baker 1974). This is the case for many "pioneer" tree and shrub species which occupy recently disturbed, scoured, or deposited sediments in and along the channels of southwestern riparian systems.

There is a high degree of variability among riparian tree species to distinct geomorphological and hydrological stream habitats (Asplund 1988). Brady and others (1985) described the development of riparian gallery forest as beginning with moist nursery bars located in overflow channels or abandoned meanders that provide moist areas for seepwillow (*Baccharis glutinosa*) to pioneer. As the stand of seepwillow develops, sediment aggradation occurs providing a seed bed for cottonwood (*Populus fremontii*) seeds, or the expansion of Gooding willow (*Salix goodingii*) roots.

The high degree of variation in stand structure and composition along a given reach in desert riparian systems is an expression of a number of variables. These include but are not limited to: flow regime, substrate, elevation, seed source, timing of seed dispersal, anthropogenic activities. Therefore, it is important to take the long-term landscape (spatio-temporal) view of these systems if we are to truly understand the complex interactions of the factors contributing to the functioning of the channel and the degree to which vegetation is expressed. In addition, the associated riparian vegetation is found along the periphery of the flood channel. The broad shallow base flows meander over the sandy alluvium often is some distance away from the riparian vegetation. Where sediments are deep, flows of low discharge may occur only below the sediment surface. In these situations, surface flow only emerges where associated with underlying shallow bedrock and percolation occurs where bedrock recedes. This intermittency is a function of channel morphology and discharge. This leads to differential expression of the associated riparian communities found along the edge of the channel at bankfull flow. When sufficiently large changes between erosion and depositional processes occur, the riparian area may be unable to adjust to change, loses its equilibrium, and in extreme cases may be permanently altered and possibly damaged (LaFayette and DeBano 1990).

These disturbance events remove most of the stream biota excluding native fishes, and bank vegetation. The magnitude of the flow determines the degree of regeneration and recruitment of the primary flora. Conversely, in the absence of such flows, the existing stand can become either senescent or can be overtaken by such species as salt cedar (*Tamarix pentandra*). Thus, one view of succession is of a temporal

nature looking at conditions at intervals reset by flows of varying magnitude and frequency. In contrast, many authors have attempted to explain these systems using a Clementsian climax succession paradigm. This concept has received considerable attention and many current classification systems strive to make these riparian habitats fit some climax succession schedule. However, this has been difficult to describe adequately and impossible to predict in these disturbance driven systems. Fisher and Minckley (1978) concluded that "an ecosystem in which the entire species pool consists of 'pioneer' species is unlikely to exhibit temporal succession." The community and how the primary species are classified thus may make application of a Clementsian model awkward if not inappropriate. Sampling and extrapolating that data to fit the balance of the study area is misleading and ineffective in describing a riparian community overall due to variability of geology, valley form and substrate. It may well be that the appropriate means to measure these sites is to evaluate the species richness and the degree of maturity or size class diversity in the particular stand over time between significant disturbance flows.

Biological Integrity

The most influential definition of biological integrity was proposed by Frey (1975) and further described by Karr and Dudley 1981. The concept is defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitat of the region" (Karr 1991).

Angermeier and Karr (1994) identified two important distinctions between integrity and diversity from this definition. First, system integrity is reflected in both the biotic elements and the processes that generate and maintain those elements, whereas diversity describes only the elements. Integrity depends on processes occurring over many spatiotemporal scales, including cellular processes giving rise to genetic elements and ecosystem processes regulating the flow of energy and materials. The second distinction between integrity and diversity is that only integrity is directly associated with evolutionary context.

When a river is dammed, integrity is reduced, resulting in population declines which are adapted to the natural hydrological regime. Integrity goals also provide for natural fluctuation in element composition. Loss of a particular element, a particular species for example, or replacement by a regionally appropriate one need not indicate a loss of integrity unless the processes associated with the element's maintenance become impaired. Biological integrity is thus generally defined as a system's ability to generate and maintain adaptive biotic elements through natural evolutionary processes. Current loss of biological integrity includes loss of diversity and breakdown in the processes necessary to generate future diversity.

Ecological Restoration

The goal of ecological restoration is to produce a self-sustaining system as similar as possible to the native biota.

Restoration goals must be based on social and political constraints as well as biological potential. Restoration methods usually mimic recovery from natural perturbations and reflect important organizational processes. Common approaches for aquatic systems include manipulating water quality, habitat structure, hydrology, riparian/watershed vegetation, and (less frequently) animal populations (Gore 1985; Osborne and others 1993). Restoration of terrestrial systems typically focuses on establishing native vegetation and manipulating succession. To maximize effectiveness, restoration efforts should employ and encourage natural ecological processes rather than technological fixes and should incorporate spatiotemporal scales large enough to maintain the full range of habitats necessary for the biota to persist under the expected disturbance regime. Riparian zones and floodplain are critical landscape components linking aquatic and terrestrial systems; they regulate aquatic habitat formation as well as movement of water, nutrients, and organic material into aquatic habitats (Gregory and others 1991).

"Restoration" may be reasonable in many cases. In other instances, enhancement of the existing altered character of our streams and rivers may be the best we can hope to realize. Most riparian habitats are now a highly controlled or altered system with much of their ecological integrity hampered by our past or continuing activities. The thoughtful application of new understandings to the delicate and intricate balance of nature, recognition of the inevitable range of flood and drought, flexibility in management and legal applications will be necessary for improvement of the riverine habitats. The solution lies in the ability to explore collaboratively means and methods to provide the societal needs while simultaneously sustaining a healthy environment. At the present time there are a number of research, monitoring, and planning activities underway designed to contribute to the overall goal of improvement of southwestern riparian ecosystems. These activities are at all levels of government and many are collaborative efforts.

Policy effectiveness also could be improved by shifting focus from populations and species to landscapes. The organizational processes and ecological contexts that maintain populations typically operate at larger spatiotemporal scales than the populations themselves (Pickett and others 1992). Thus management approaches focusing on strictly aquatic components (for example, designation of a stream reach as wild and scenic or as critical habitat for an imperiled species) are unlikely to be effective over the long-term.

Dr. Hal Salwasser in 1991 made the observation that traditional agricultural, fisheries, forestry, game management, and mining agencies must replace their narrow, commodity and harvest-oriented philosophies with innovative perspectives founded on a broader range of social concerns, longer time frames, and more interagency cooperation. Critical steps toward managing for biological integrity include establishing scientifically defensible benchmarks and assessment criteria. (Angermeier and Karr 1994). Although these steps are potentially contentious, current uses of integrity goals indicate that success is attainable.

The morphic variables that interact to form the dimensions, profile and patterns of modern rivers are often the same variables that have been adversely impacted by development and land use activities. To restore the disturbed

river, the natural stable tendencies must be understood to predict the most probable form. If one works against the natural tendencies of a river course in terms of watershed yield, morphology, and channel and meander geometry. If one works against these tendencies, restoration is generally not successful (Rosgen 1994).

Restoration efforts in the uplands, river corridor, in the floodplain, on public, private and tribal lands is ever increasing. We are instituting Adaptive Management in many arenas to recreate habitat which has been lost or whose quality has been severely affected by our past management activities.

The solution at first blush appears to be either too simplistic or too overwhelming. Clear understanding of what is needed, the operating space for change in administration, and recognizing that we are all part of a basin wide community will provide opportunities to be better stewards of the finite resources we utilize.

Societal Choices

The causes of environmental degradation and loss of biodiversity are rooted in society's values and the ethical foundation from which values are pursued. Solutions are likely to emerge only from a deep-seeded will, not from better technology. Adopting biological integrity as a primary management goal provides a workable framework for sustainable resource use, but fostering integrity requires societal commitment well beyond government regulations and piecemeal protection. Such a commitment includes self-imposed limits of growth and resource consumption, rethinking prevailing views of land stewardship and energy use, and viewing biological conservation as essential rather than as a luxury or nuisance. The decision to conserve or exhaust biotic resources is before us. It can be informed by science and influenced by government policy, but conservation primarily depends on a societal will grounded in recognition of its obligation to the future. (Angermeier and Karr 1994).

Quality of life does reside in a healthy environment. There are numerous economic benefits associated with vibrant, functioning ecosystems. Responsible management and administration at all levels of government and as individuals will be necessary. But without attention to these aspects, significant and perhaps irreversible consequences could result. Ultimately, the habitat we save will be our own.

References

- Angermeier, P. L., and J. R. Karr., 1994. Biological Integrity versus Biological Diversity as Policy Directives: Protecting Biotic Resources. *BioScience* Vol. 44.
- Asplund K., 1988. Reproduction and Geomorphic Adaptations in 4 Species of Riparian Cottonwoods in Central Arizona. Arizona/New Mexico Wildlife Society Joint Meeting. Thatcher, Arizona.
- Baker, H.G., 1974. The evolution of weeds. *Annu. Rev. Ecol. Syst.* 5,1-24.
- Bell, D.T., 1974. Tree stratum composition and distribution in the stream side forest. *American Midland Naturalist.* 92:35-46.
- Bormann, F.H., and G.E. Likens. 1979. "Pattern and Process in a Forested Ecosystem." Springer-Verlag, Berlin and New York.
- Brady, W., D.R. Patton, R. Paxson, and J. Paxson. 1985. The development of Riparian Gallery Forests. In: *Riparian Ecosystems and Their Management; Reconciling Conflicting Uses*. First N. Am. Rip. Conf. USDA F.S., Rocky Mtn. Forest & Range Exp. Station. GTR-RM-120 39-43.
- Bullard, T.F. and S.G. Wells. 1992. Hydrology of the Middle Rio Grande from Velarde to Elephant Butte Reservoir, New Mexico. U.S. Fish and Wildlife Service, Resource Publication 179.
- Connell, J.H., 1979. Tropical rain forests and coral reefs as open non-equilibrium systems. In "Population Dynamics" (Anderson R., B. Turner, and L. Taylor, eds.), pp. 141-163. Blackwell, Oxford.
- Crawford, C.S., A.C. Cully, R. Leutheuser, M.S. Sifuentes, L.H. White, and J.P. Wilbur. 1993 Middle Rio Grande Ecosystem: Bosque Biological Management Plan.
- Denslow, J.S., 1980. Gap partitioning among tropical rainforest trees. *Biotropica* 12, suppl., 47-55.
- Ellis, L.M., J.R. Thibault, M.C. Molles, Jr., and C.S. Crawford. 1995. Effects of Flooding on Woody Debris Biomass and Decomposition in a Southwestern Riparian Forest. In Review: *Canadian Journal of Forest Research*.
- Fisher, Stuart B. 1986. Structure and Dynamics of Desert Streams. In: *Pattern and Processes in Desert Ecosystems*, W.G. Whitford (editor). University of New Mexico Press pp 119-139.
- Fisher, S.G., and W.L. Minckley. 1978 Chemical characteristic of a desert stream in flash flood. *Journal of Arid Environments.* 1:25-33
- Forman, R.T.T. and M. Godron. 1986. Landscape ecology. New York: John Wiley and Sons.
- Frey, D. 1975. Biological integrity of water: an historical perspective. Pages 127-139 in R. K. Ballentine and L. J. Guarraia, eds. *The Integrity of Water*. EPA, Washington DC.
- Gore, J. A., ed. 1985. *The Restoration of Rivers and Streams*. Butterworth, Boston, MA.
- Graf, W.L. 1982. Spatial variation of fluvial processes in semiarid lands, in Thorn, C.E. (ed), "Space and Time in Geomorphology." George Allen & Umvin, New York. 193-277.
- Gregory, S.V., F.J. Swanson, W.A. McKee, and K.W. Cummins. 1991. An Ecosystem Perspective of Riparian Zones. *BioScience*, 41, 540-550.
- Grubb, P.J., 1977. The maintenance of species-richness in plant communities: the importance of regeneration niche. *Biol. Rev. Cambridge Philos. Soc.* 52, 107-145.
- Hill, M.T., W.S. Platts, and R.L. Beschta. 1991. Ecological and geomorphological concepts for instream and out-of-channel flow requirements. *Rivers*, 2, 198-210.
- House, K.P. 1993. The Arizona Floods of January and February 1993. In *Arizona Geology: Vol. 23, No.2, Summer 1993*.
- Karr, J. R. 1991. Biological integrity: a long neglected aspect of water resource management. *Ecological Applications* 1:66-84.
- Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. *Environ. Manage.* 5:55-68.
- Lafayette R.L., and L.F. DeBano. 1990. Watershed Conditions and Riparian Health: Linkages. Watershed Planning and Analysis in Action Symposium Proceedings of IR Conference, Watershed Mgt./IR Divi./American Society Civil Engineers (ASCE). Durango, CO/ July 9-11, 1990 pp 473-484.
- Leopold, L.B., M.G. Wolman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco.
- Levin, S.A. 1992. The problem of pattern and scale in ecology. *Ecology*. 73: 1942-1968.
- Meyer, J.L., W.H. McDowell, T. L. Bott, J.W. Elwood, C. Ishizaki, J. M. Melack, B. L. Peckarsky, B.J. Peterson, and P.A. Rublee. 1988. Elemental dynamics in streams. *J.N.A. Benthol. Soc.* 7(4):410-432.
- Osborne, L. L., P. B. Bayley, and L. W. Higler, eds. 1993. Lowland stream restoration: theory and practice. Special issue. *Freshwater Biol.* 29: 187-342.
- Pickett, S. T. A., V. T. Parker, and P. L. Gieldler. 1992. The new paradigm in ecology: implications for conservation biology above the species level. Pages 65-88 in P. L. Fiedler and S. K. Jain, eds. *Conservation Biology*. Chapman & Hall, New York.
- Pickett, S.T.A., and P.S. White. 1985. The Ecology of Natural Disturbance and Patch Dynamics. Academic Press Inc., New York. 53-68.

- Poff, N.J., and J.V. Ward. 1989. Implications of streamflow variability and predictability for lotic community structure; a regional analysis of streamflow patterns. *Can. J. Fish. Aqua. Sci.*, 46, 1805-Platt, B., Schanta M., Lachowski, H., Maus, P. Landrum, V., and Jan Johnson. 1992. Forest Plan Monitoring: Role of Remote Sensing and GIS on the Mark Twain National Forest. National Workshop-Integrated Ecological and Resource Inventories, Phoenix AZ. WO-WSA-4. April 1992.
- Poff N.J., J. D. Allan, M.B. Bain, J.R. Karr, K. L. Prestegard, B.D. Richter, R. E. Sparks, J. C. Stromberg. 1997. The Natural Flow Regime: A Paradigm for River conservation and Restoration. *BioScience*. June 1997
- Rosgen, D.L., 1994. A classification of natural Rivers. *Catena* 22 pp164-199
- Salwasser, H. 1991. In search of an ecosystem approach to endangered species conservation. Pages 247-265 in K. A. Kohm, ed. *Balancing on the Brink of Extinction*. Island Press, Washington, DC. Schindler, D. W. 1990. Experimental perturbations of whole lakes as tests of hypotheses concerning ecosystem structure and function. *Oikos* 57:25-41.
- Stromberg, J.C., and D.T. Patten. 1990. Riparian vegetation instream flow requirements: a case study from a diverted stream in the eastern Sierra Nevada, California. *Environ. Manage.*, 14,185-194.
- Stromberg, J.C., and D.T. Patten, 1991. Instream flow requirements for cottonwoods at Bishop Creek, Inyo County, California, *Rivers*, Vol. 2, pp 1-11.
- Stromberg, J.C., D.T. Patten, and B.D. Richter. 1991. Flood flows and Dynamics of Sonoran Riparian Forests. *Rivers*, Vol. 2, Num. 3. pp 221-235.
- Stromberg, J.C. 1993. Instream flow models for mixed deciduous riparian vegetation within a semiarid region, *Reg. Riv.: Research & Management*, Vol. 8, 225-235.
- Szaro, R.C. 1989. Riparian and forest and scrubland community types of Arizona and New Mexico. *Desert Plants* 9:70-135.
- Tilman, D. 1982. *Resource Competition and Community Structure*. Princeton Univ. Press, Princeton, New Jersey.
- Tyus, H.M., 1990. Effects of Altered Stream Flows on Fishery Resources. *Fisheries*, vol. 15, No. 3 pp 18-20.
- Urban, D.L; R. V. O'Neill, and H. H. Shugart, Jr. 1987. Landscape ecology: a hierarchical perspective can help scientist understand spatial patterns. *BioScience*. 37: 119-127.
- Urban, D.L., Gardner, R.H., R.V. O'Neill, and S. M. Pearson. 1993. Landscape Ecology-a hierarchical perspective can help scientists understand spatial patterns. *BioScience* 37: 119-127.
- Webb R.H.; J.L. Betancourt. 1992. Climatic Variability and flood Frequency of the Santa Cruz River, Pima County, Arizona. U.S. Geological Survey-Supply Paper 2397, U. S. Govt. Printing Office, Washington D.C.
- Whitney, J.C. 1996. Integration of GIS and Remote Sensing in the Evaluation of Flood Disturbance on the Upper Verde River, Arizona. Masters Thesis, Arizona State University.
- Zimmerman R.L., Plant Ecology of an arid Basin, Tres Alimos-Reddington Area, U.S. Geol. Surv. Prof. Pap. 485-D, U.S. Govt. Printing Office, Washington D.C.