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Restoration of Wetland and Riparian Systems: The Role of Science, Adaptive Management, History, and Values

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Riparian and wetland ecosystems have been extensively altered with increasing human demands for more available land for agriculture, water management, resource extraction and urbanization. More than fifty percent of the original wetlands in the United States were lost by the 1980s and more have been lost or greatly altered since (Gibbs 2000), while more than ninety percent of the riparian areas have been altered or lost (Kentula 1997). Recent realization that these ecosystems provide many beneficial services to both humans and natural processes has elevated the concern for their losses or degradation. Laws such as the Clean Water Act recognize the importance of wetlands and require protective action when wetlands are disturbed. Concern for water quality and wildlife habitat, as well as recreational potential, has encouraged individuals and communities to restore or rehabilitate those wetlands and riparian areas that have not been totally extirpated, and where lost, attempts are being made to recreate these systems.

Restoration is not solely a scientific effort. Several concepts have been developed that should be considered when addressing restoration activities (National Research Council 1992). These include the role of science and policy, an understanding of historic perspectives, and adaptive management. To be successful, restoration has to occur within the constraints of the biophysical and sociopolitical worlds. Ignoring the interplay between these two "worlds" will not only create problems for the restoration practitioner, but potentially end in failure.

This paper discusses several components critical to restoration success, initially addressing the importance of the scientific process in developing restoration goals, and then showing the importance of adaptive management, understanding historic conditions, and the role of social and political inputs to the effort. All of these components must come into play if there is to be a hope for restoration efforts to be successful.

The Role of Science

One often hears the statement that restoration will be based upon "good science." What is "good science," or more specifically how should science be used in a restoration activity? Science, or better, scientific research, allows us to develop an understanding of the ecological processes of undisturbed and altered wetland or riparian ecosystems. This includes understanding how perturbations have altered the ecosystem of interest. We need to address fundamental questions like, what should we be aware of, what should we learn, and how do we act? Considering that most degradation that influences wetlands and riparian areas has occurred across large areas, often as big as whole watersheds, it is critically important to look beyond a specific site when considering a restoration action, and yet most restoration activities tend to be site or reach specific (Bond and Lake 2003).

What should we be aware of? There are many external and internal processes that drive wetland and riparian systems. Understanding the role or influence of these processes is essential to developing restoration goals that will have long-term success, rather than short-term success and long-term failure. One of the most important external drivers is climate.

This includes long-term macro-climatic patterns as well as regional or meso-climatic processes often controlled by regional physiography (e.g., mountains, valleys). Macro-climatic patterns tend to be cyclical meaning that restoration efforts in a wet period may not survive in an ensuing dry period. Several continental climatic cycles have different periods of occurrence, and yet both drive climatic patterns that will greatly influence success or failure of wetland or riparian restoration. An example of a longer climate cycle, the Pacific Decadal Oscillation (PDO), is often several decades long and has produced extended warm dry and cool wet periods for western North America (Mantua and Hare 2002). A short-term cyclical climate pattern which is perhaps better understood by the public and policy-makers is the El Nino/Southern Oscillation (ENSO). ENSO has short cycles of a few years (often a one year maximum preceded or followed by years with reduced effects). In the West, ENSO differentially produces wet winters in the north and dry winters in the south, or vice versa (Ropelewski and Halpert 1986). The immediate success or failure of riverine restoration efforts might be greatly influenced by ENSO events, for example, restoration that requires high spring flows might fail if the ENSO cycle produces a dry winter (i.e., low snow pack and thus low spring runoff).

Not as regional as climate cycles, but certainly as important, are riverine landscape components that not only drive or determine restoration outcomes but also are attributes that respond to restoration efforts. When primarily considering riverine restoration efforts, condition of the watershed and uplands is critical (Bond and Lake 2003). As mentioned, most landscape changes extend well beyond the river, riparian or wetland system into the watershed. Changing land cover and land use in the watershed will greatly alter associated watershed hydrology and thus inputs to wetlands or riverine systems. Inability to address, or lack of attention to, altered watersheds and upland conditions as well as upstream conditions may make riverine restoration efforts futile, or produce only short-term successes. Rivers may be a product of their watershed, but an understanding of all riverine landscape attributes is essential to returning a non-functional, altered system into a functional system with all or most ecosystem processes. Connectivity among riverine attributes, especially between river and floodplain, is a natural function of the riverine system, one that should be preserved and/or restored.

Hydrological processes play such an important role in creating and maintaining wetlands and riverine systems that prior to any restoration effort, hydrological features of both the location to be restored and the associated watershed need to be understood. These should include both surface and ground water processes and conditions. Hydrological processes can be quite variable depending on latitude, and regional physiography and climate. Seasonal differences in flow magnitudes, even at the same latitude (often a response to heterogeneity of mountain terrain) determine what riparian systems occur along rivers (Patten 1998). Regional or latitudinal hydrological differences also become important in determining restoration approaches. For example, snowmelt rivers, common in the Rocky Mountains, have discharge peaks in spring. In contrast, rivers in the Southwest are often "flashy" in that hydrological peaks occur in spikes following seasonal rain events. These rivers may have occasional high discharge peaks in winter during long-duration cyclonic storms.

Hydrology interacts with valley geomorphology to create different channel types. For example, stream gradient and maximum flow regimes combine to produce different channel configurations (Leopold et al. 1964). Attempts to produce channel types that would not naturally occur may result in restoration failure. Rivers are dynamic and river migration, especially in valleys with low gradients and unconstrained channels, is expected. Restoration efforts that attempt to constrain migrating river channels tend to produce non-functional riparian or floodplain ecosystems. Riverine restoration that "works with" the natural dynamics of the river has the best chance for long-term success.

Latitude also plays a role in channel formation and successful riparian establishment. Ice drives common in northern rivers (Auble and Scott 1998) may scour the bank and the lower floodplain preventing riparian restoration in these areas. Successful riparian vegetation recruitment occurs in river bank zones above ice-drive levels (Smith and Pearce 2000).

Understanding "natural" biological processes in wetland or riparian areas is essential to restoration success. Many restoration efforts include "undoing" habitat alteration such as change in land use, stabilized river banks or channelization. Most of these alterations have eliminated or altered natural biotic processes such as riparian vegetation recruitment along river channels and point bars, overbank flooding to stimulate asexual reproduction of riparian vegetation, or development of secondary channels as locations for juvenile fish refugia and riparian vegetation establishment (Richter and Richter 2000). Recognizing that the riverine system is an integrated and complex ecosystem is essential to restoration success. For example, studies on the upper Yellowstone River show that juvenile fish habitat and riparian recruitment have similar and overlapping requirements (Bowen et al. 2003, Merigliano and Polzin 2003). High flows into secondary channels, along point bars, and overbank enhance both juvenile fish survival and riparian vegetation, while low flows along modified river banks (e.g., rip rap) might provide suitable protection for juvenile fish but prevent riparian establishment. Many other biological components of the riverine system such as avian communities are dependent on products of flows and channel types, especially as they influence the riparian zone.

Identifying Stressors

Wetland or riparian restoration often begins with removal of stressors that have altered the system. Here science may not be needed to identify the stressor (e.g., grazing), but once identified, simply altering or removing it (i.e. passive restoration) may be all that is needed for restoration. The potential success of passive restoration, however, depends on understanding the magnitude of the stressor (normally a research activity) and designing restoration activities accordingly. One should also recognize that most stressors and drivers of wetland and riparian systems are interactive or synergistic (Figure 1). Certainly, human-oriented stressors greatly influence each other

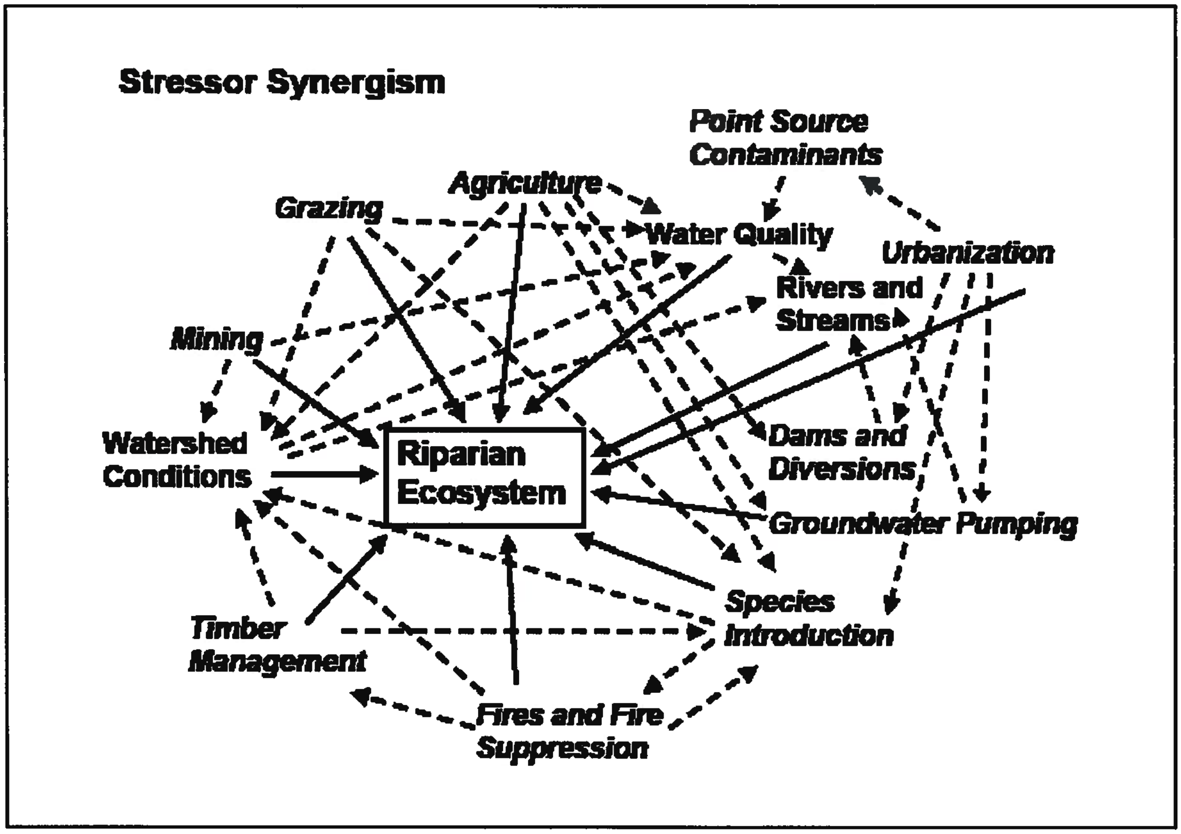

Figure 1. A conceptual diagram showing direct (solid arrows) and indirect (dashed arrows) anthropogenic (italics) and natural stressors and drivers on riparian ecosystems. The diagram emphasizes the synergistic aspect among stressors and the importance of understanding these interrelationships when considering riparian (or wetland) restoration.

as well as the primary watershed and hydrological drivers of wetland or riparian systems. Which stressors should be considered most important when setting goals for wetland and riparian restoration? Although the list can be extensive and Figure 1 shows many potential ones, only a few will be discussed here. Discussion of others can be found in Patten (1998) and other sources.

Urbanization and Road Development

Human expansion beyond cities and along rivers is rapidly altering wetlands and riparian areas that once were regional recreation areas or wildlife habitat (May and Homer 2000). New developments near rivers not only make demands on water resources but reduce infiltration surfaces and cause stream incision (Booth and Reinelt 1993), while producing effluent and runoff that alters water quality (Stromberg et al. 1993). Local roads and buildings alter wildlife migration routes and modify natural vegetation communities through elimination of natural vegetation and introduction of exotic species. Valley bottoms and tracks along rivers have been used as primary transportation routes for centuries. Small roads and trails probably had little effect on rivers and wetlands, while expansion of highways and multi-lane freeways along old transportation corridors has resulted in constraints on river migration, deposition of waste and toxic materials into rivers, and reduction of riparian and wetland habitat adjacent to the roadway. Bank stabilization associated with roads and bridges has caused rivers to down cut reducing ground water levels near the river and increasing river flow velocities (Booth 1990).

Agriculture and Ranching

Agriculture has long been one of the primary alterations of wetlands and riparian areas (Zedler 2003). Wetlands often are filled in, drained or plowed over. Riparian vegetation once extended kilometers from the river onto floodplains that have been cleared for farming or pasture, reducing the riparian zone to little more than a strip. Grazing in unaltered riparian zones often reduces the vegetation cover resulting in barren stream beds and depauperate floodplains (Kauffman and Krueger 1984). Cattle often spend much more time in riparian areas than uplands when access to the river and riparian area is available.

River Channel Alteration.

Land ownership along rivers often results in flooding threats to property, homes and other structures or amenities (Nilsson and Berggren 2000). Migrating rivers tend to cut into one side of the channel and build up the other (e.g., point bars). Property owners dependent on products from the land, or protection of facilities, find loss of land to be unacceptable. They therefore resort to measures that stabilize the river bank, such as rip rap, or redirect the river away from eroding banks, such as barbs and weirs. All of these efforts alter the natural flow of the river and modify habitat for aquatic and riparian biota.

Altered Hydrographs

Water management has been a regular part of human expansion and agricultural development in arid regions as well as along rivers in more mesic areas where water power was harnessed for industry. Dams and diversions greatly change the downstream condition of aquatic and floodplain ecosystems which may lead to extensive and expensive restoration efforts illustrated by experimental floods in the Grand Canyon (Webb et al. 1999, Patten et al. 2001). Dam operations are designed to produce power and supply water to downstream users based on use schedule, not natural hydrological flow patterns. The result may be loss of natural spring, high-flow peaks, critical biological triggers for many aquatic and riparian species, increase in base flows, and loss of down stream sediment pulses that accompany high flows (Poff et al. 1997, Magilligan and Nislow 2005). Altered hydrographs, sometimes with no flows, have resulted in greatly altered riverine ecosystems (Rood and Mahoney 1990), in some cases so altered that only costly restoration, including change in dam operations or decommissioning of dams, can reverse the impacts (Rood et al. 2005). The Glen Canyon Dam studies and experimental flood (e.g., Patten et al. 2001), and stream diversion and eventual recovery after water releases into feeder streams to Mono Lake (National Research Council 1987, Stromberg and Patten 1990) are good examples of effects of altered hydrology and restoration efforts.

Ground Water Withdrawal

Arid regions are often very dependent on ground water resources for urban and agricultural development (e.g., Las Vegas demands for deep aquifer water in eastern Nevada). Ground water supports springs and isolated wetlands in arid regions and maintains base flows of rivers in regions with limited or seasonal rainfall. Ground water withdrawal has the effect of lowering alluvial water tables on which riparian vegetation is dependent (Stromberg et al. 1996), reducing base flow of streams (Scott et al. 1999) and potentially drying up springs and isolated wetlands (Schaefer and Harrill 1995). In most arid regions, withdrawal of ground water greatly exceeds recharge resulting in a continued decline of the regional water table and reduction in volume of large regional aquifers. Eventually, overdraft of ground water will result in reduced agriculture, loss of wildlife from areas with limited water sources such as springs, and extensive water conservation for urban areas greatly dependent on ground water.

The preceding discussion has addressed the scientific understanding of ecosystems that might be considered for restoration. Emphasis was placed on understanding natural processes and how they are "broken" or altered. Of equal importance is recognition of factors or stressors that cause alterations and how these might be acting synergistically to influence or maintain the altered system. Using a scientific approach, restoration choices, whether passive, active or a combination, can be determined (Figure 2). This approach would work well in a world where all decisions were made only on scientific information; however, the real world (i.e. the one with people with many interests and values) requires that restoration take into account these social and economic values when making restoration decisions. The following discussion brings these factors into play within an adaptive management approach, and includes historic evidence in the decision-making process.

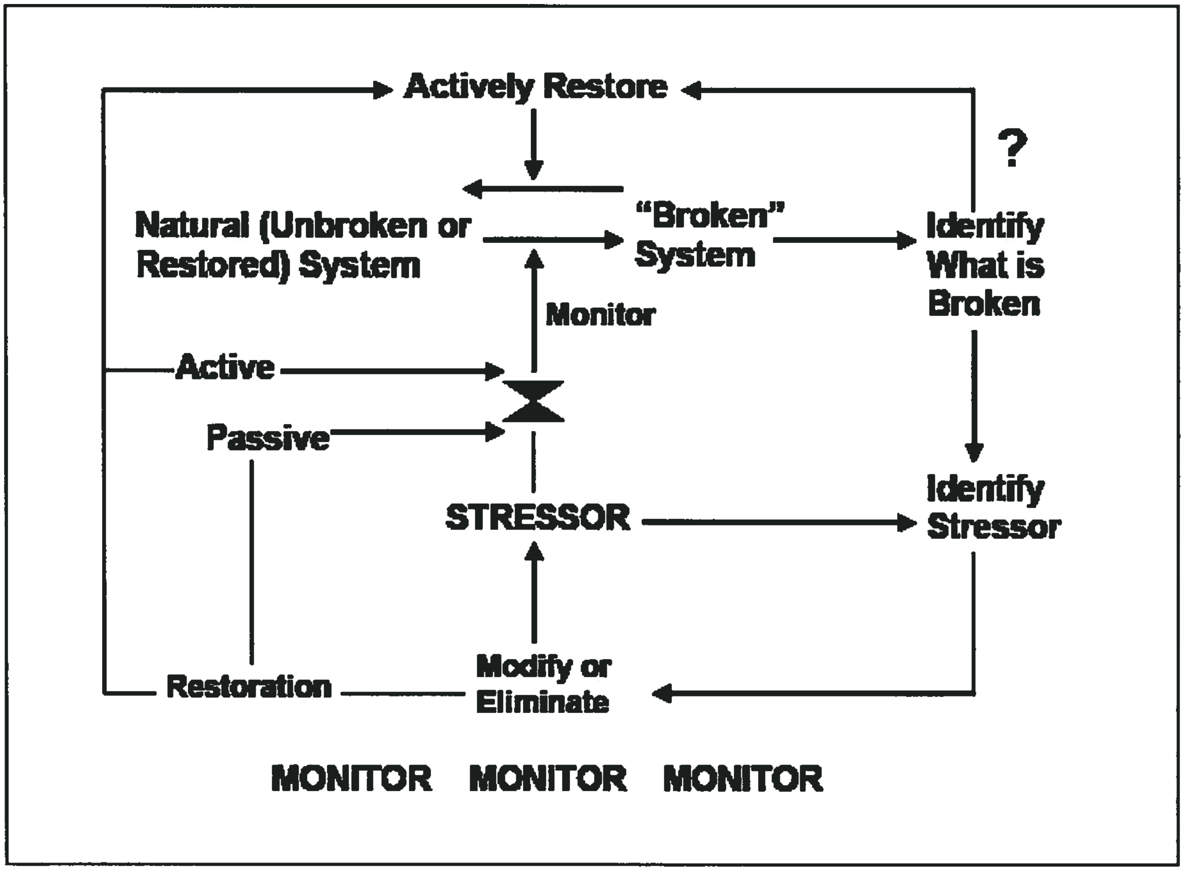

Figure 2. Conceptual diagram of restoration procedures based primarily on science. This includes steps such as identifying stressors, reducing or fixing them through a selected format of restoration (i.e., passive, active or both). It emphasizes the need to monitor at every step.

Adaptive Management

Science has been the emphasis of the discussion on restoration goals, but how does science play into decisions on restoration management and activities? We know that restoration should be based on a scientific foundation in that we should understand the ecosystem to be restored as well as the influence of the stressors or perturbations that have caused the system to be non-functional. But, is it sufficient to have a portfolio of scientific data to begin restoration, or are there other conditions that need to be addressed? Recent development of approaches to restoration through adaptive management, a concept developed by Walters (1986) and applied to riparian systems (Walters 1997), allows us to understand the steps needed for successful restoration efforts. Adaptive management, in a general sense, has been practiced for some time as resource managers and restoration practitioners adjust their approaches as they learn from past activities. However, adaptive management goes well beyond "learning from doing." Adaptive management requires setting goals, reviewing available information and determining appropriate actions before implementing full-scale restoration (Figure 3). It also includes a monitoring component that allows managers to evaluate outcomes and reconsider approaches. For all restoration actions, monitoring plays a critical role

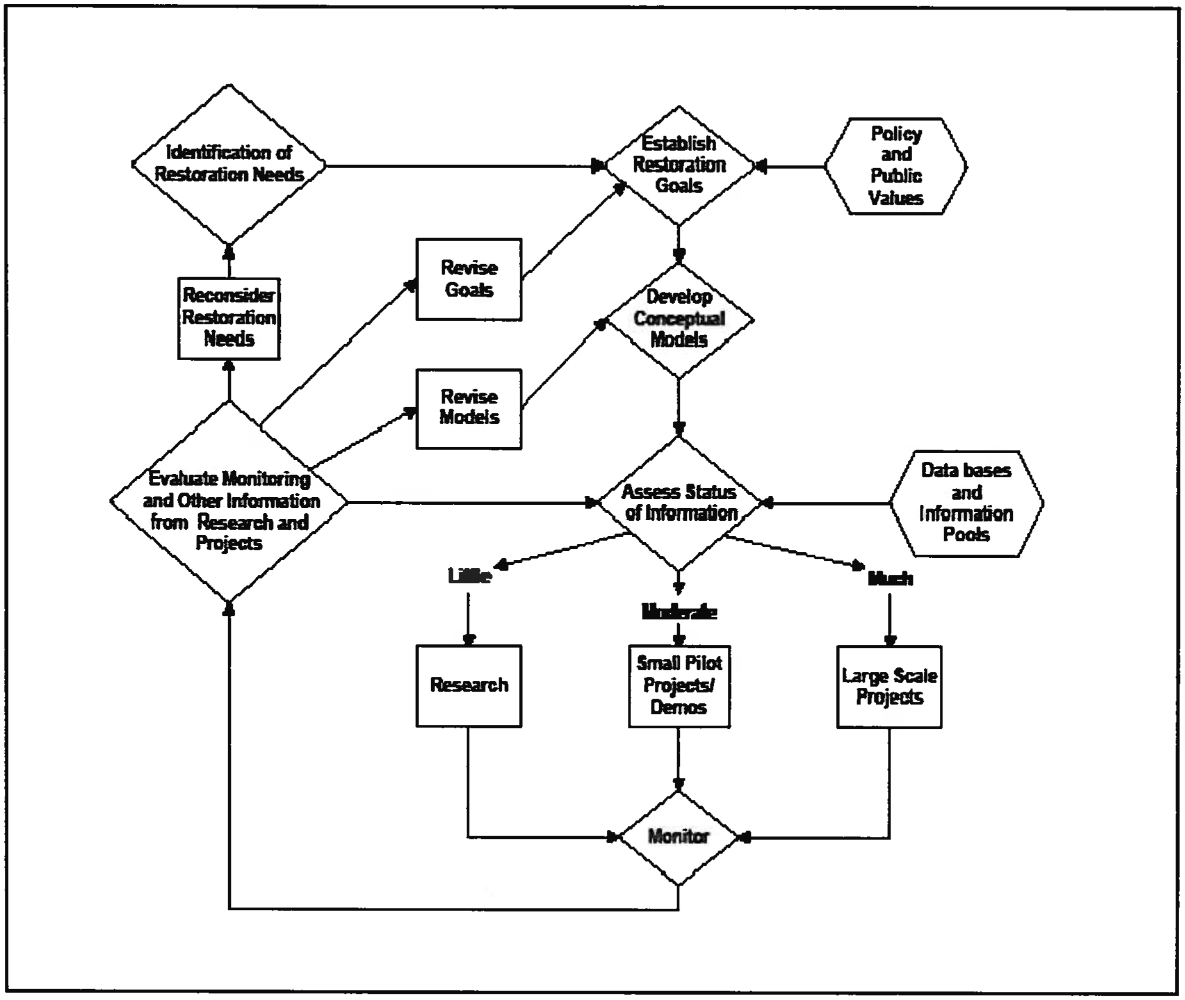

Figure 3. An adaptive management model to guide restoration activities. The model includes scientific data and public policy inputs. Decision points are in triangles. Adaptive management as depicted in this model shows feedbacks and alternative decision activities that will improve potential for restoration success. Model format is adapted from California Bay Delta Authority Ecosystem Restoration Program Proposal Solicitation Package.

in the learning process. Monitoring must also be of sufficient duration to allow assessment of long-term results. Assessing existing data prior to restoration is also critical because proceeding with restoration on insufficient data may result in failure, while recognizing a lack of comprehensive information may lead to additional research to fill data gaps and, consequently, eventual restoration success.

Adaptive management emphasizes the importance of understanding the system to be restored and completeness of data prior to restoration. If the ecosystem processes are understood, we should be able to predict the direction of restoration responses or outcomes. Sarr (2002) suggests several models that, if adhered to, would help guide decisions on whether to continue restoration activities. The "rubber-band" model has the recovering system responding back along the same trajectory as when it was being degraded. Passive restoration actions, such as removal of cattle from riparian areas, often produce this response. The "humpty-dumpty" model shows that, once broken, the changes are irreversible and the system cannot return to a pre-degraded condition no matter what restoration efforts are applied. The "broken-leg" or hysterisis model shows that recovery of a degraded system does not follow the same trajectory as during degradation but rather recovery lags for some time after removal or reduction of a stressor, eventually occurring as the system returns to pre-degradation conditions. Many restoration projects follow this model because recovery is long-term, emphasizing the need for long-term monitoring to assess restoration success.

If restoration knowledge predicts the "humpty-dumpty" model, it would be worthless to spend time and funds on restoration. If predictions follow the hysterisis model, serious consideration must be given to how much time, effort and funds are worth putting into the restoration activity.

Historical Perspectives

Restoration activities require an image of the condition of the future endpoint, the restored system. This future endpoint may be a condition dictated by public values as well as ecological constraints discussed later, but, in many cases, the endpoint is based on reference processes and conditions found at reference sites. Should reference conditions be based on preferred conditions, or "pristine" conditions (i.e., conditions considered to be natural with absence of human disturbance or alteration (Hughes 1995)), or should they be ignored in favor of restoring altered systems to their ecological potential within present day constraints of environment, public values, polices, etc.? If reference conditions are to be the guide, there are several ways of determining them: (a) oral, written and photographic history; (b) aerial photographs and Landsat images (but these may not be sufficiently "historical"), and (c) "undisturbed" reference sites that still have all or most ecosystem functions and do not appear to be degraded. Most ecologists would prefer the latter approach as this allows study of these reference sites and produces information that will guide appropriate restoration actions. Brinson and Reinhardt (1996) state that "by establishing standards from reference wetlands chosen for their high level of sustainable functioning, gains and losses of functions can be quantified for wetlands used in compensatory mitigation," that is, restoration..

The problem with using reference sites, or even "point-in-time" images such as aerial photos or repeat photography, is that these do not allow interpretation of the historic range of variability (HRV) through which ecosystems progress over time in response to changing environments. Today's ecosystems are the product of both natural and human disturbances in addition to normal ecosystem dynamic processes such as succession and competition (Figure 4). The plasticity of ecosystems to changing environments in the past has been within HRV, whereas recent environmental changes have, perhaps, pushed ecosystems outside their HRV. There have been many efforts to determine the HRV of ecosystems, in most cases upland ecosystems that have responded to fire or insect damage (e.g., Veblen et al. 1991). Historical ecology based on approaches such as repeat photographs and historic documentation has guided these efforts. Little, if any, documentation of the HRV of wetlands and riparian areas is available. This may be a result of these systems being small or linear, very dynamic or extremely vulnerable to droughts and changing regional hydrology. Swetnam et al. (1999) stated that "although applied historical ecology is an evolving field, there appears to be a building consensus that, at a minimum, it is very useful to know and understand the past to properly manage (and restore) ecosystems for the future."

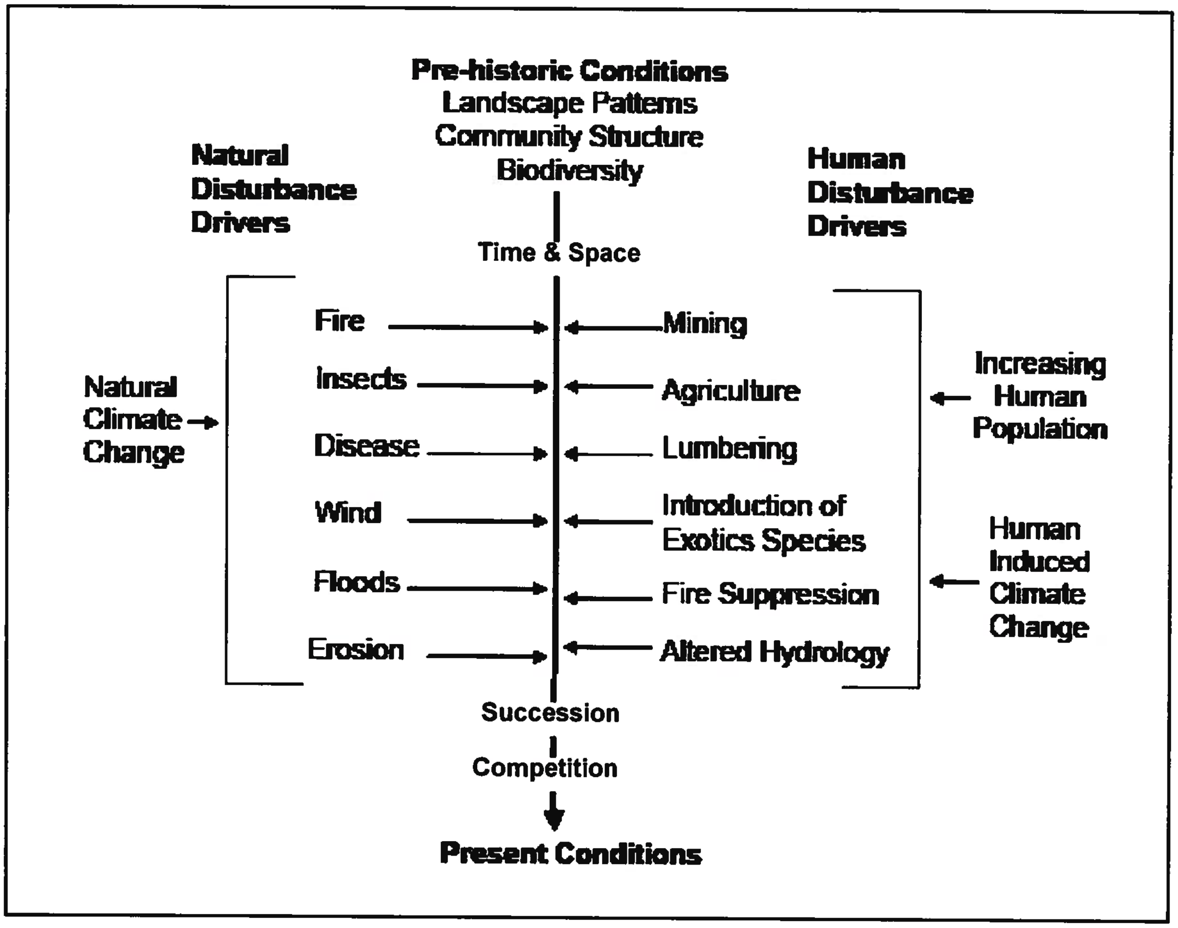

Figure 4. Diagram of natural and human disturbance drivers that have altered the landscape over space and time producing present-day conditions. Restoration activities need to consider most of these disturbance drivers although potential to modify natural disturbance drivers may be difficult.

Public and Policy Inputs

The adaptive management diagram (Figure 3) shows the importance of public inputs and policies in setting restoration goals. McLain and Lee (1996) point out that "adaptive management can fail if non-scientific forms of knowledge and policy processes promoting shared understanding with stakeholders are discounted." Including the public creates partnerships or "buy-in" for developing restoration efforts. It brings in local and regional interests, cultures and economics, all important to designing a restoration project that is acceptable to science and the public. When the public is included and resource managers and restoration practitioners listen, a level of trust is developed that allows all avenues for setting goals to be explored. Scientific information, when communicated in an understandable fashion, becomes more acceptable and less threatening to the public. Bringing the public and policy-makers directly into restoration planning by discussing interrelationships among different scientific efforts and public activities, and including them in workshops and field trips, all enhance potential for public acceptance of management decisions and restoration efforts.

Establishing desired wetland and riparian conditions following public input may conflict with scientific information on historic or natural variability of the ecosystems of interest. The public may desire a condition that is similar to the altered condition and not one that would revert back to some natural condition of the past. Landres et al. (1999) has described the potential conflicts and management actions needed when natural variability, current condition, and desired future condition are all considered at the same time. They point out that when natural variability is equivalent to desired and current conditions, management action should be one of maintenance, whereas when current condition is not equivalent to natural variability or desired condition, restoration should be considered. They also explain that when the above relationships do not exist, the system should be carefully evaluated relative to risks, sustainability, and external subsidies needed to maintain a desired future condition. In addition, social objectives for the desired future condition (e.g., public value inputs to restoration goals) might also be reevaluated.

Conclusions

This paper offers guidelines for restoration of wetland and riparian systems founded, in part, on use of adaptive management concepts. In summary, a set of conclusions one should draw from this paper are listed. One must remember that accompanying this list is the recommendation that monitoring must be part of the process at nearly every step of restoration. Here are my recommendations:

1. Understand ecological functions of the system to be restored and the reference system.
2. Work with stakeholders, policy makers and the public.
3. Understand the historic background of the system to be restored including ecology and human activities.
4. Research, learn, test ideas, adapt, reconsider conceptual ideas and try again.
5. Consider passive restoration before active restoration.
6. Eventually, if enough is known, proceed with a big restoration project.
7. Monitor, monitor, monitor.

In summary we should remember that science develops understanding of processes and perturbations, policy develops directions and constraints, and the public develops values, perceptions, and acceptable endpoints. If all of these are included, restoration should be a successful endeavor.

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