The Middle Rio Grande Bosque:
An Endangered Ecosystem

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Abstract

The Middle Rio Grande bosque originated about two million years ago. This riparian forest and the river that created and maintained it have greatly changed during their long history. Ecological change during the 14th through 20th centuries was caused by climatic cycles and increasingly intensive use of the floodplain and the river first by Pueblo Indians, then by Spanish and finally Anglo settlers. Hydrological change began in the 1800s with watershed exploitation that generated erosion and flood-borne sediment deposition. This led to valley flooding and raised floodplain groundwater to unacceptable levels. Practices that mitigated these events and simultaneously met the increasing demand for water by basin and downstream communities resulted in extensive regulation of the Rio Grande's hydrology. Consequently, the bosque is no longer a mosaic of cottonwood-willow stands of different ages located at different distances from a relatively sinuous river channel free to move across the floodplain. Rather, the bosque is now mostly a linear strip of native and exotic trees that is "disconnected" from the flow-regulated, straightened river that floods its banks much less frequently than before. Consequent changes in the bosque's ecological dynamics are rapidly leading to an ecosystem that, in terms of its structure and functioning, will undergo irreversible change in the absence of a new management paradigm.

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Introduction

The Middle Rio Grande flows in moderately sinuous fashion between Cochiti Dam and Elephant Butte Reservoir in central New Mexico (Figure 1). Between these two 20th century impoundments the river's riparian (streamside) zone supports a nearly continuous "bosque" (forest) of native and introduced vegetation (Figure 2). For the most part, levees on both sides of the river divide the bosque longitudinally, and, as we shall see, functionally as well. Beyond the levees the wide floodplain is covered by pueblos, cities and towns, farms and clusters of trees that sometimes border its many irrigation canals. Ponds and marshes are rare.

In contrast, the relatively unconstrained Middle Rio Grande of a thousand or more years ago probably would have meandered more and certainly, over the millennia, would have moved back and forth across the floodplain as heavy snowmelt or storm-generated runoff plugged old channels with water-borne sediment and created new ones. These movements would have left behind a mosaic of cottonwood and willow bosques (Figure 3) originally created and maintained by overbank flooding. The presence and abundance of wetlands near and beyond the riparian zone would have depended on the climate of the time, since the functioning of the entire ecosystem was driven then, as it is now, by the interaction of atmospheric moisture with basin hydrology.

We know much more about the riparian forest along this one-eighth of the river's length than we do about what remains along its other reaches. Historical accounts are one reason for this; another is the acknowledged decline of the ecological integrity of this longest continuous stretch of cottonwood forest in the Southwest (Crawford et al. 1993, Howe and Knopf 1991). That condition and its projected outcome have motivated ecologists and resource managers to explore and monitor the role of the bosque ecosystem in the context of the basin of which it is a part.

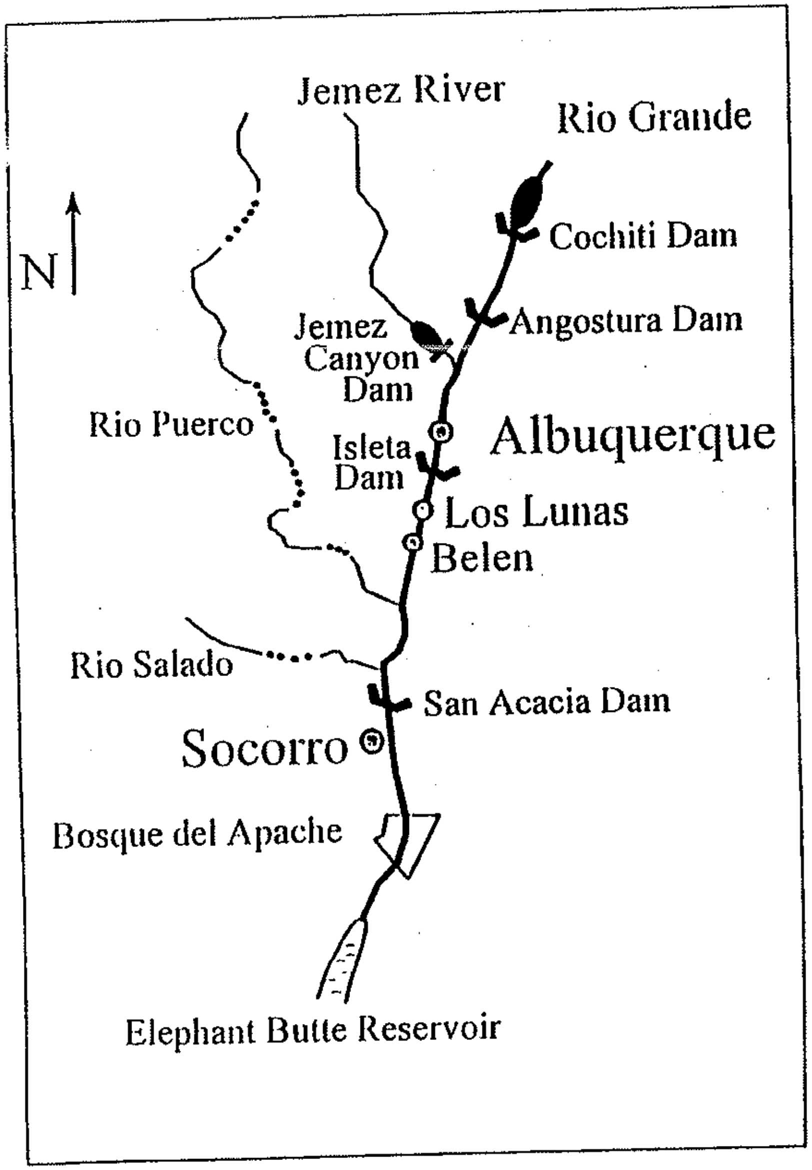

Figure 1. Diagram of the Middle Rio Grande showing approximate locations of major impoundments, diversion dams, tributaries, human communities and Bosque del Apache National Wildlife Refuge.

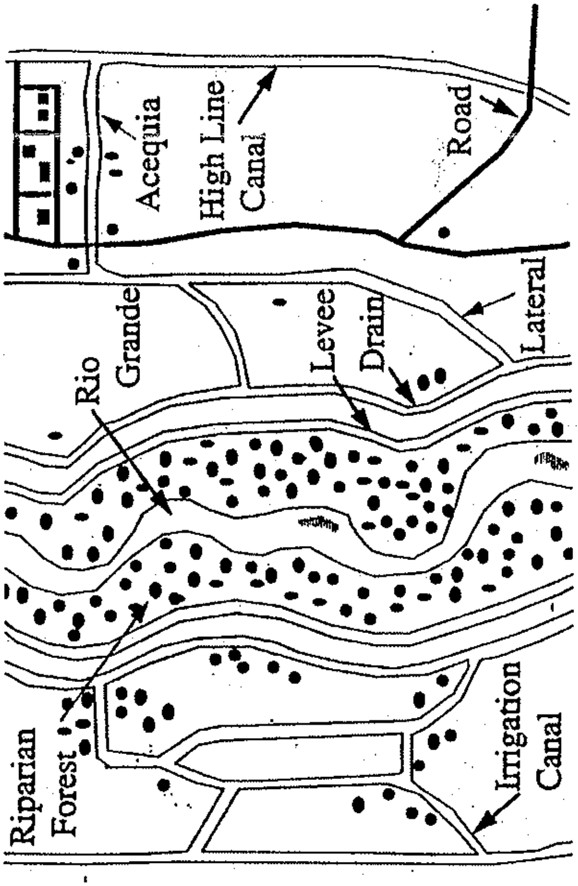

Figure 2. Diagram of landscape features typically found in the Middle Rio Grande Valley of the 20th century.

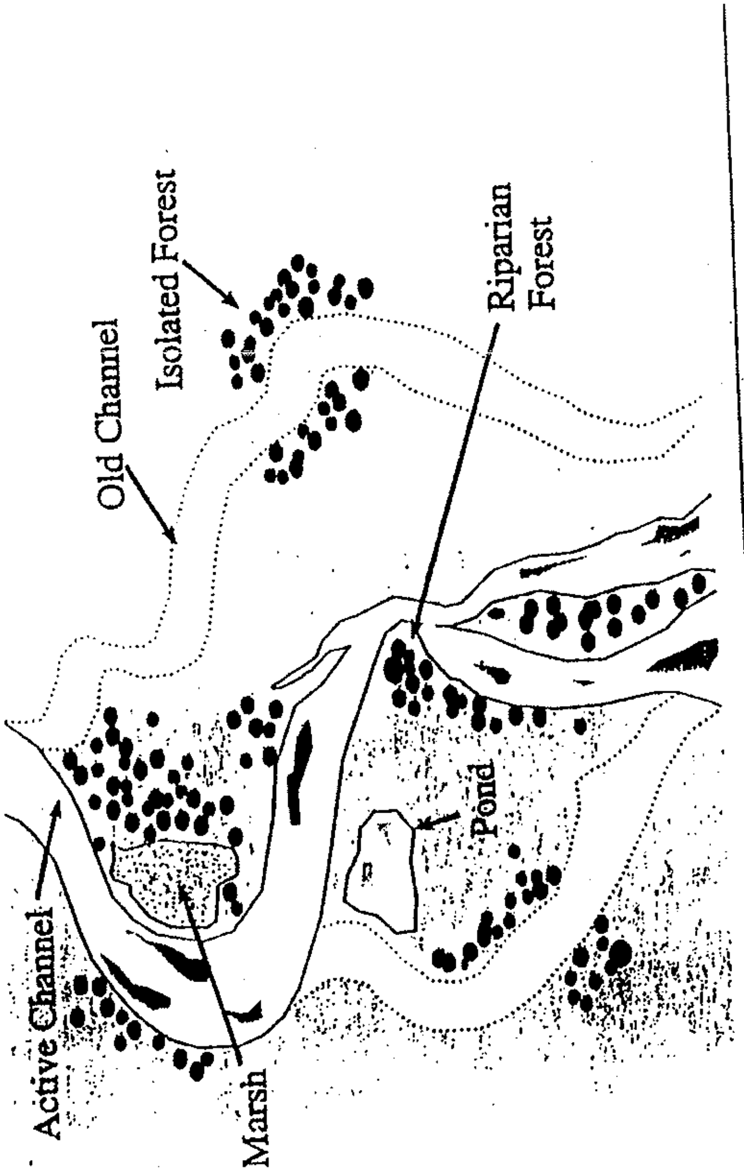

Figure 3. Diagram of landscape features assumed to have been typical of periods with at least average precipitation a thousand or more years ago in the Middle Rio Grande Valley.

Knowledge of the past allows us to better understand the dynamics of the present. Therefore, we begin this account with an ecological review of the history of the Middle Rio Grande bosque.

Bosque Ecology Before the 20th Century

Ancestors of the Rio Grande bosque's native vegetation existed in the Southwest by the mid-Miocene, about 14 million years ago (Axelrod and Bailey 1976). According to fossil evidence, a true cottonwood forest was present by the early Pleistocene, about two million years ago (Knight et al. cited in Crawford et al. 1993). By the time humans first encountered the bosque, some 10,000 to 20,000 years ago, the climate of the Southwest was relatively cold and wet and vegetation now occuring at higher elevations covered much of the Rio Grande valley (citations in Dick-Peddie 1993). The presence of fossil emergent plants such as cattails tells us that ponds and marshes also occurred in the floodplain (Knight et al. cited in Crawford et al. 1993).

The Rio Grande above El Paso probably began at least two million years ago with the integration of separate, ephemeral lakes set in linked depositional basins along the axis of the great Rio Grande Rift (Bullard and Wells 1992, Lozinski et al. 1991). During its existence as a free-flowing river, what is now the Middle Rio Grande progressively built its broad floodplain on the surface of deep, sedimentary and volcanic rock deposits in the rift (Kues and Callendar 1986, Bullard and Wells 1992). During the last million years or so, a newer assortment of sediments was deposited in a series of incision and back-filling episodes that eventually created the channels and floodplain deposits of the present inner valley (Lozinski et al. 1991).

Once formed, the river carried materials derived from watershed soils into these channels, where they settled in patterns dictated by the relationship of particle size to flow energy. The multilayered composite of sand, silt and clay that resulted was regularly eroded and rearranged by floods resulting from snowmelt and rainstorms. The chronic instability of this substrate, coupled with the dynamics of the flowing water that created it, would influence the spatial and temporal distribution of the floodplain's riparian communities until humans entered the picture many centuries later.

Historically, cottonwood-willow forests along the Rio Grande and other Southwest rivers began their chance-filled lives on flood-scoured banks during late spring and early summer, when and if the timing of their seed release coincided with high water flows. First, the seeds had to land on banks that were clear of shade from larger trees. Then, if post-flood soil moisture subsided at about 0.5 cm/day (value inferred from Segelquist 1993), the growing roots of newly germinated seedlings would have remained moist until the declining soil moisture reached the capillary bed above the water table. More rapid subsidence of soil moisture would have caused the seedlings to dehydrate and die. Prolonged inundation would have killed them by oxygen deprivation, and recurring heavy floods would have washed them downstream. Clearly, the historic establishment of the river's riparian vegetation must have been regulated by the vagaries of climate, as wet and dry seasons and years replaced each other over the centuries and millennia.

Such would have been the environment, between about 7,000 and 2,000 years ago, encountered by PaleoIndian hunter-gatherers venturing off the western mesas into the Middle Rio Grande Valley. Centuries later, for reasons not fully understood, some of their relatively sedentary Anasazi descendants moved into the Middle Rio Grande Valley. The new colonists established pueblos and initiated a scale of community living that far exceeded anything attempted earlier in the valley (Tainter and Tainter 1995). Their intensive farming also marked the beginning of significant ecological change in the floodplain because they must have cleared considerable valley land, thereby altering the distribution and abundance of many native plants and animals in the floodplain (Tainter and Tainter 1995). However, their immediate ecological effects were spatially concentrated because they still practiced traditional floodwater farming, which utilized high flows and did not divert water to more distant locations (Wozniak 1995).

The arrival of Spaniards in the Middle Rio Grande Valley in the 1500s had a greater impact on the floodplain and its bosque. These new settlers introduced irrigation farming, which they imposed on the Pueblo inhabitants (Wozniak 1995). Huge tracts of riverine landscape were cleared for agriculture, presumably at a significant cost to the riparian forests.

The introduction of livestock also led to ecological change in the middle valley. The effects of sheep, goats and cattle in particular on native vegetation can be inferred from what we know of their later impact on a variety of southwestern ecosystems (Dick-Peddie 1993). Young riparian cottonwoods, in particular, are still a favorite food of cattle (Szaro 1989, Rood and Mahoney 1990).

Increased numbers of settlements during the 17th and 18th centuries were promoted by land grants from the Spanish government. This led to more irrigation farming and livestock herding, which took their toll on riparian ecosystems via stream flow alteration and additional tree removal (Wozniak 1995).

The vitality of the middle valley was and still is influenced by relatively short-term climatic cycles. Periods of drought can last for more than a decade in the Southwest and tend to reappear every few decades (Molles and Dahm 1990). During the Spanish Colonial Period they destroyed crops, decimated wildlife and depleted water supplies (Scurlock 1993). Such droughts also influenced the demography and distribution of human populations in the valley, which would have had indirect effects on the structure and functioning of the bosque ecosystem.

Like drought, floods also devastated the valley's human communities. Records of flooded villages and farmland going back to 1591 show that such events were not uncommon during the colonial period (Scurlock 1993). Extensive valley flooding would have occurred when heavy spring rains accompanied rapid snowpack melting. Whatever social disruption these floods may have caused, they would also have recharged the floodplain's water table, saturated newly formed seedbeds, allowed fish access to nutrients released by flooded detritus on the forest floor, and accelerated nutrient fluxes in the bosque soil.

The occupation of the Middle Rio Grande Valley by the United States in 1846 probably had no immediate effect on the ecology of the river and the bosque, the latter being depleted in places but still having impressive stands south of Isleta (Scurlock 1993). Irrigation farming and livestock herding remained the principal occupation of communities in the floodplain, although the region's economy was gradually undergoing the changes described below (Wozniak 1995).

Changes impacting the river and the floodplain had been occurring in the surrounding mountains since the early 1820s with trapping for beaver, which were virtually extirpated from the upper watersheds by the late 1830s (deBuys 1985). With beaver dams in disrepair, streams swollen by heavy summer rains became conduits for sediment gouged from their beds and banks. As a result, runoff intensity increased (Findley 1987), as did sediment transport out of the mountains and into the bed of the Rio Grande and its main tributaries.

Increased emphasis on cattle grazing, logging and mining in basin uplands also affected the river and floodplain. These enterprises were intensified by the arrival of railroads which, beginning in the late 1870s, greatly increased the scope of human immigration from and resource export to the Midwest and East (Wozniak 1995). Soil disturbance by each of these activities was considerable, and probably made a major contribution to the sediment load in the Rio Grande from the late 1800s on. Sedimentation in the Upper and Middle Rio Grande was also exacerbated by the rapid development of irrigation agriculture in the San Luis Valley of Colorado (Wozniak 1995). This reduced downstream flow, causing water-borne particulates to settle out sooner than when the river carried more water and flowed faster. Thus, increased erosion in the watersheds and deposition of sediment in the river channel aggraded (raised) the channel bed downstream. This steepened the hydrologic gradient between the river and the floodplain and forced floodplain groundwater to rise, waterlogging cropland. Paradoxically, concurrent flow reduction caused the river below Albuquerque to dry up for months at a time. Irrigation practices that seldom returned water to the river simply added to the waterlogging problem (Wozniak 1995). Evaporation from waterlogged fields brought dissolved salts to the surface, which devastated crops and probably impeded the germination and survival of much riparian vegetation. According to historical accounts, cottonwoods were relatively scarce south of Albuquerque in the late 1800s due to human use, destructive flooding and stand abandonment by the shifting river channel (Scurlock 1993).

Meanwhile the floodplain's high water table created many ponds, marshes and wet meadows in the middle valley, which in turn supported a high diversity of plants and animals. Most likely these wetlands benefitted many vertebrate animals such as coyotes, fence and whiptail lizards that hunt insects attracted to wet banks and mallard ducks that nest in the forest. Territorial muskrats living in holes along banks had substantial habitat, as did a variety of terrestrial and aquatic invertebrates. But the chain of events that created the wetlands was about to be interrupted as human residents of the floodplain reached the limits of their tolerance of waterlogging and flooding.

The Bosque Since the Early 1900s: Effects of River Regulation

The visible consequences of the floodplain's hydrological imbalance called for technological solutions to the worsening conditions. At the same time, application of these solutions had to contend with competing claims for the river's water. The following cursory description of some of the administrative structures and legal agreements that were instituted to deal with these claims and to support water regulation in the Middle Rio Grande Valley can be supplemented by reading more complete accounts (e.g., Shupe and Folk-Williams 1988, Bokum et al. 1992, Bullard and Wells 1992).

The three hydrological conditions needing remediation were irrigation, drainage and flooding, all interrelated consequences of human activity and climatic variability. The Middle Rio Grande Conservancy District (MRGCD) was formed in 1925 to cope with these conditions. Inadequate irrigation was corrected by constructing a dam and storage facilities on the Rio Chama and diversion dams and many kilometers of main irrigation ditches in the middle valley, and by rehabilitating many older acequias (Crawford et al. 1993).

To correct the drainage problem, the MRGCD built an extensive system of drainage canals (Crawford et al. 1993). Located below the local water table, they remove water from the aquifer, river and irrigation ditches. During periods of low river flow, water can be diverted to the drainage canals, which then become conveyance canals. These were intended to reduce the surface area of water in the main river channel, and thereby to reduce evaporation and leakage (Wilkins 1986). Intercepted flows are returned either to the irrigation system or to the river, thus circumventing one of the causes of waterlogging.

From an agricultural standpoint, improved irrigation and construction of a drainage system did much to correct the problems they were devised to combat. From a hydrological standpoint, the reorganized water distribution system of the middle valley in effect lowered but also recharged the shallow groundwater over a wide area. Shallow groundwater recharge had previously been achieved by the river, but less evenly in time and space, because the river periodically changed course.

However, from an ecological standpoint, drainage terminated the existence of most of the middle valley's wetlands within about a year of canal construction in the early 1930s, and had a drastic effect on much of the valley's biota (Van Cleave 1935). Plants and animals once dependent on wetlands for survival may have been locally extirpated and were redistributed within remaining or new aquatic habitats. In a very few years, a smattering of wet meadows, marshes, ponds and seeps, together with irrigation ditches and drains, became refugia for previously widespread species of aquatic plants, invertebrates, and habitat-specific vertebrates such as leopard frogs and meadow jumping mice. Many of these "new" habitats were located either in or adjacent to the bosque.

Flood control also had far-reaching effects. The basic flood control structures included levees that paralleled the middle river everywhere except along its east bank south of San Acacia. Between 1951 and 1977, lines of bolted girders called Kellner jetty jacks were installed by the Bureau of Reclamation between the levees and the river to protect them and to aid in flood control by arresting moving sediment and debris. Jetty jacks were sometimes positioned in the river so that sediment trapped behind them would accumulate and form a new bank. This straightened the river and stabilized its banks; it also created new areas for plant establishment (see Figure 29 in Crawford et al. 1993).

The main flood control structures, however, were dams, which also controlled sediment transport. The Flood Control Acts of 1948 and 1960 authorized the construction and operation of a number of dams that would directly and indirectly regulate flows above and below Elephant Butte Reservoir, built in 1916 largely to supply water to downstream interests. Compact agreements, first with Mexico in 1906 and then with Texas and Colorado in 1923, had guaranteed that water would be delivered between and among those political entities at certain rates. The 1948 Act also authorized the construction of a low-flow conveyance channel between the San Acacia Diversion Dam and Elephant Butte Reservoir. Situated just outside the western levee system, the "Low-flow" was designed to deliver water downstream when the river was low, and by so doing to minimize water loss to infiltration and riparian trees (Bullard and Wells 1992). For the most part, however, it functions as a major drain of shallow groundwater and is an important source for the removal and return of irrigation water. The Low-flow is also an especially valuable source of water for wetland management at Bosque del Apache National Wildlife Refuge, which maintains by far the most extensive wetlands along the Middle Rio Grande.

The most significant ecological effect of the numerous dams above Cochiti, and certainly of Cochiti Dam itself, was to diminish the river's historic flooding regime. The last great flood along the river was in 1941, when flows of up to 25,000 cubic feet per second inundated downtown Albuquerque. Wet banks along the receding waters allowed that year's crop of cottonwood seeds to become the progenitors of most of today's native bosque overstory trees. Cochiti Dam, built in 1975, ended any possibility of such an extensive cottonwood recruitment in the foreseeable future.

Dams trap sediment and the relatively clear, fast moving water they release deepens the channel and cuts its banks sharply for some distance downstream (Williams and Wolman 1984, Rood and Mahoney 1990). Currently, the bed of the channel between Cochiti and Corrales has been lowered to the point of precluding cottonwood seedling establishment except on a few exposed banks and silt bars. Consequently, lengthy flooding of the bosque inside the levees at peak runoff above Albuquerque appears to be a thing of the past.

In contrast, the opportunity for overbank flooding inside the levees increases with distance below Albuquerque because of the river's gradual bed aggradation and relatively sloping banks (Crawford et al. 1993). Thus even in Los Lunas, portions of riverside forest become flooded in high-runoff years. Heavy sedimentation, provided especially by the Rio Puerco, greatly increases the likelihood of overbank flooding south of Bernardo. However, in very low runoff years like 1996, much of the river is dry in late spring and no overbank flooding is possible anywhere along the Middle Rio Grande.

Finally, another assault on the ecology of the bosque that intensified during the 20th century but began much earlier was the introduction of exotic species. Domestic livestock and foreign crop plants were imported by early Spanish colonists. Also, two seldom-noticed species of terrestrial isopods, native originally to the Mediterranean Basin but now nearly ubiquitous, have become an integral part of the bosque's leaf litter fauna. Starlings and house sparrows, introduced to North America in the last century, are an unwelcome presence throughout the bosque as are house mice and feral cats. A variety of introduced forbs such as yellow sweetclover and horseweed have surely been part of the riparian scene for many years (Crawford et al. 1993).

The dominating exotics, however, are trees, and the most overwhelming of these in terms of its conquest of the bosque is saltcedar or tamarisk. Saltcedar, like the abundant Russian olive, was introduced early in the 20th century. It has extensively colonized vast portions in the southern half of the middle valley, where its monocultures have taken over riparian forests and abandoned fields, and now extend up the channels and banks of major tributaries. Nearly impenetrable to humans, saltcedar stands are popularly felt to support little wildlife. However, several recent studies have shown that those stands support an abundance of birds, small mammals and ground dwelling arthropods (Ellis 1995, Ellis et al. 1996, Ellis et al. in press).

Russian olive makes its major impact in the northern half of the middle valley. It is most visible as dense grey patches that line the river's banks and crowd out other vegetation. Unlike saltcedar, it also does well beneath shady cottonwood canopies. Russian olive is not entirely detrimental, however, since its roots have nodules containing nitrogen-fixing microorganisms, and thus its leaves add nitrogen to the soil when they fall (Crawford et al. 1993). Further, many birds eat its fruit.

Other woody exotics include Siberian elm (which could well become the dominant tree in the Corrales and Los Lunas bosques in another 50 years), ailanthus (which now forms narrow groves along levees) and mulberry (which is quite common in the Las Lunas bosque). Collectively, these introductions should replace most of the bosque's cottonwoods in the next century if current management practices persist (Knopf and Howe 1991, Crawford et al. 1993).

Bosque Ecology: The Current Picture

Climate and human history, largely through their influence on basin hydrology, together have transformed the bosque ecosystem of the Middle Rio Grande. The bosque's present appearance and functioning reflects the greatly altered condition of the river and the shallow aquifer. Human use of the floodplain, together with flow regulation, levees and exotic introductions have compressed much of the bosque into a nearly continuous, linear forest that little resembles its ancestral state. Dry and wet cycles still affect basin hydrology, but while most riparian communities along the middle river respond as expected to drought, they no longer experience the regenerating, nurturing and destroying effects of overbank flooding.

Our current assessment of the riparian forest's ecology is based partly on the pioneering analysis of Hink and Omart (1984), and largely on more recent research by ourselves and our colleagues at the University of New Mexico (Ellis 1995; Ellis et al. 1986, in press; Lieurance et al. 1994; Molles et al. 1995). Here we summarize our impressions in the context of our experimental flooding studies at the Bosque del Apache National Wildlife Refuge.

Despite its linearity, the bosque is a complex ecosystem. Enter it at 10 different points between its upstream and downstream boundaries and, if you look around carefully, you will see as many unlike habitats. You will also detect differences inside and outside the levees. Then, too, you will find open spaces ranging from glades to small fields within the forest, and in many places you will see signs of disturbance by humans and cattle. Seldom will you encounter a site that lacks exotic vegetation.

To make sense of these observations we distinguish between two categories of bosque that differ in the extent of their hydrologic connectivity with the river (Figure 4). "Disconnected" stands are isolated from the river's influence and are generally outside the levees. What we call "steady state" stands, in contrast, are influenced by the river and are usually located within the levee system. Like many descriptions in ecology, these are simplistic designations, as connectivity must vary in space and time. But the categories do allow us to appreciate how hydrology organizes the bosque ecosystem, which we now explore as two component subsystems: the forest floor and the aboveground environment.

The forest floor

The floor of the disconnected forest is usually covered by a dense layer of dead leaves and wood. This thick, carbon-rich energy source

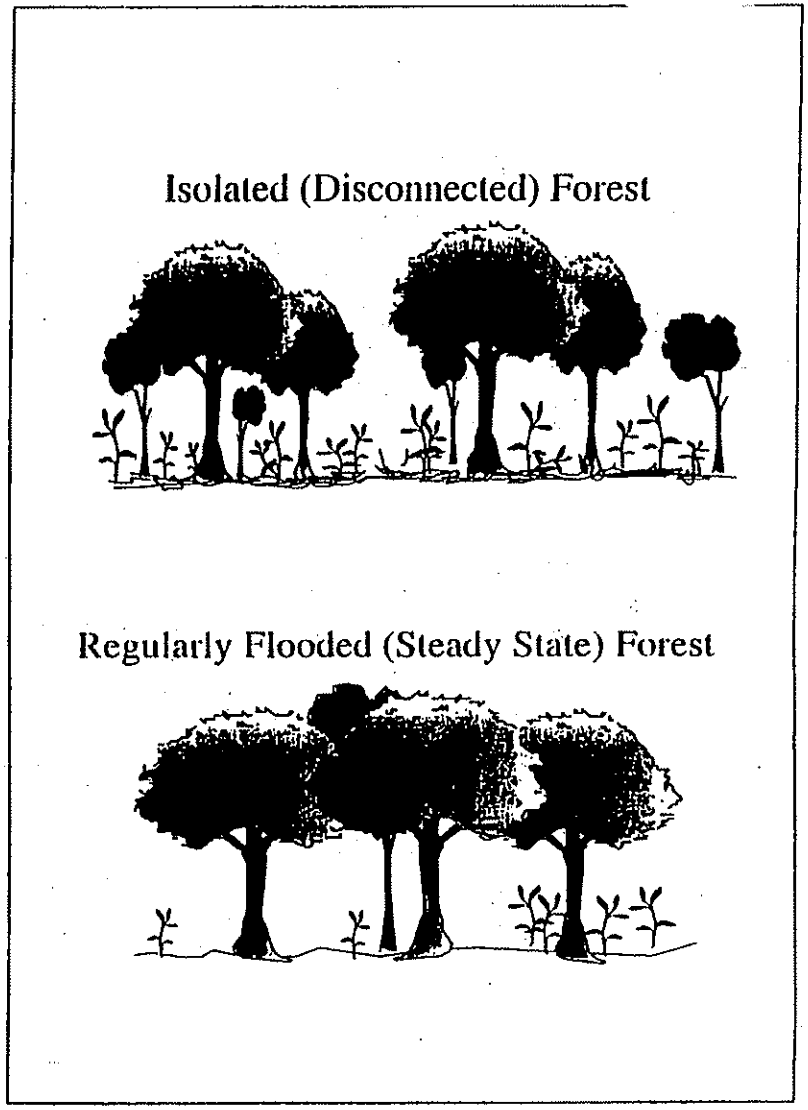

Figure 4. Diagram of two categories of Middle Rio Grande bosque that differ in the extent of their hydrologic connectivity with the river. Note differences in amounts of cottonwood canopy, densities of understory trees and shrubs, densities of herbaceous vegetation and depths of leaf litter and woody debris.

decomposes more slowly than it accumulates when deprived of seasonal flooding, thus creating a mass of dry, combustible material and trapped nutrients. Over the last decade, this increasing fuel load has contributed to an increasing number of wildfires in the bosque (Stuever et al. in press).

Common animals that make use of this habitat include seed- and insect-eating white-footed mice, seed-caching rock squirrels, and ground-foraging birds like towhees and sparrows. Fence and whiptail lizards are the principal reptilian insectivores. Many species of omnivorous ants and darkling beetles also inhabit the soil and litter, as do a variety of spiders and a smaller set of carnivorous beetle species. Isopods abound in deep leaf litter and beneath logs. As in the steady state forest, tiny springtails and mites are major players in the complex food web, while microscopic nematode worms graze on soil bacteria.

The soil-litter interface of the disconnected forest is a visible gradient of fragmented organic material that disappears at the depth of a trowel scoop. Mineral soil may range from clay to sand. Depending on how the river deposited sediment when the present forest floor was its bed, further excavation may reveal unstructured soil interrupted by depositional "lenses" of sand, silt or clay. These layers, sometimes run through with tree roots, constitute the soil column down to the water table two or three meters below. Grey-blue clays and sulphurous smells signify low oxygen levels at the capillary fringe just above the water table.

In the disconnected forest, most of the soil column's biological activity occurs in the upper 10 to 20 centimeters, a zone where pocket gophers push up piles of excavated soil along their shallow tunnel systems. These animals eat underground plant parts and green surface vegetation (Findley 1987). They function like earthworms, which are seldom seen except in wet conditions, in their capacity to turn over soil. Omnivorous camel crickets and many smaller arthropods spend most of their lives in the tunnels of pocket gophers.

Fungi and bacteria on and just beneath the forest floor are the primary agents of decomposition and mineralization of fragmented dead plant tissue throughout the bosque. In the absence of floodwater these processes proceed slowly, even during the warm monsoon season. Nitrate and ammonium are mineralized products of decomposed protein used both by soil microorganisms and the shallow root systems of disconnected cottonwoods. The latter harbor mycorrhizal fungi that facilitate nutrient and water uptake. However, since the amount of available soil nitrogen regulates fine root production in cottonwoods (Pregitzer et al. 1995), and since otherwise available nitrogen is tied up in slowly decomposing litter, fine root production is likely to be reduced in disconnected forest cottonwoods (D. Rowland, personal communication).

The forest floor environment in a regularly flooded riverside forest is quite different. It is covered by less leaf and woody litter, both of which decompose more rapidly, whether exposed during flooding or buried by flood-borne sediment. Diminished litter means less shelter for foraging rodents and birds than there is in the disconnected forest. Pocket gopher activity is low to nonexistent in a forest that floods regularly; however, white-footed mice, which are expert tree climbers, appear to be little affected by flooding.

Cracks caused by the drying of flooded soils are readily used by a surface-active arthropod fauna dominated by a species of riparian cricket and a relatively species-rich and abundant assemblage of mostly carnivorous ground beetles. The same two isopod species occur in the river forest as in its isolated counterpart, but in lower numbers. Ants are represented by fewer species; the most abundant one nests in the rotten cores of cottonwood trunks and forages high in trees, protected from floodwater below.

The soil-litter interface is also very different in the steady state forest. Fallen leaves left over from the previous flood are skeletonized and covered with a film of sediment. The superficial soil has a well developed "crumb" (aggregated particle) structure, signifying strong microbial activity. Carbon, which provides the energy for that activity, is more concentrated in steady-state forest soil than in disconnected forest soil. The opposite is true for the cations sodium and potassium: they are diluted by flooding, which therefore makes the soil more productive.

Lens positioning in the soil columns of the two forest types is extremely varied. In the one riverside site we study, an impermeable layer of fine deposit prevents the entire column from being wetted during a flood. While this is not the case in our experimentally flooded site outside the levee (authors' unpublished observations), neither site may be typical of all connected or disconnected forests. Oxygen-poor conditions again occur at the capillary fringe in riverside soils, but highly oxygenated floodwater creates an aerobic environment during surface inundation. Microbial respiration, indicating biological activity, increases dramatically at the soil-litter interface as the river flows over the bosque floor. However, the increase is much greater when the disconnected forest is flooded for the first time in decades — and when the stored carbon suddenly becomes an energy source. Microbial decomposers of cellulose appear to be most abundant in flooded forest soil. Microbial biomass, and the capacity for root colonization by mycorrhizal fungi that aid plants in nutrient absorption, are generally highest there, too. On a year-to-year basis, the flux of energy and matter in the soil and litter of the steady-state bosque greatly exceed that of the disconnected bosque.

The aboveground environment

Cottonwoods still dominate the overstory of most of the Middle Rio Grande bosque. Depending on their age and history of stress, cottonwoods in a stand of disconnected bosque range from being stunted and densely packed to tall and well separated. Some may be formed from root suckers and therefore may be part of a genetic clone. The cause of their clonal reproduction is not always clear, nor is their age-to-size relationship. Regardless of their size and density, trees in the disconnected forest have canopies that provide moderate shade.

Canopy shade, leaf litter depth, soil moisture and other factors influence the distribution and abundance of understory plants in the bosque. In disconnected stands, understory trees and shrubs crowd the forest. Shade-tolerant exotics such as Russian olive, Siberian elm and mulberry, as well as native Gooding willow, New Mexico olive, silver buffaloberry, seep-willow, false indigo and screw-bean mesquite, may be present at a given site. Saltcedar, which is somewhat shade-intolerant, may occur there too; dense clusters of it sometimes occupy space where cottonwoods are absent. The same is true for mature coyote willow, which like saltcedar and New Mexico olive is one of the most widespread understory trees in the disconnected Middle Rio Grande bosque. Grasses and forbs tend to inhabit relatively open, litter-free locations wherever they occur in the bosque. An interesting exception is yerba mansa; normally a plant of marshy habitats, it grows in shaded soils covered with deep leaf litter inside the levee near Corrales and Los Lunas.

Cottonwood stands in the steady state bosque generally consist of relatively large, well separated trees. The canopy is usually dense and provides much shade. The saltcedar understory, sometimes abundant, has poorly developed foliage. Few other plant species occur there, especially in regularly flooded locations. Why? Flooding may be the indirect answer, because, for reasons discussed above, it makes nutrients available to cottonwoods which as a result grow tall and have complete canopies. The resulting shade inhibits understory germination.

Bosque trees are home to a rich assortment of animal species, the great majority of which are insects and other arthropods. Migratory neotropical birds mix with local species in the spring, summer and fall. Both rely heavily on arthropod protein, which many glean from the leaves, twigs and bark of woody vegetation. Current studies demonstrate that cottonwood, saltcedar and Russian olive harbor fairly dissimilar arthropod communities, which means that foraging birds can choose from several different menus (M.J. Meyerson, personal communication). It will be interesting to see whether the decline of the cottonwoods affects the composition of the visiting and resident avifauna. Large predatory and omnivorous birds may also be affected by the change, since great-horned owls and Cooper's hawks often nest—and wild turkeys typically roost—in large cottonwoods. A variety of hole-nesters use dead snags or dead branches on living trees.

Cottonwoods can be stressed by defoliating insects. New leaves in the spring lack sufficient defensive compounds to deter outbreaks of certain leaf-rolling moth larvae, as well as the larvae and adults of the cottonwood leaf beetle. This beetle, especially, can account for the premature shedding of around half of a tree's leaf biomass (K. Eichhorst, personal communication). The heaviest outbreaks seem to be in the Albuquerque area, where cottonwood leaves in the summer and fall are now densely covered with dark fungus-generated spots. The intensity of these assaults on the leaves of the bosque's most prominent tree diminish with distance from the city, reminding us that directly or indirectly, the fate of this ever-changing riparian forest is now mainly in the hands of a single species that arrived late in the long history of the great river.

Conclusions

From this partly speculative ecological history of the Middle Rio Grande bosque one message stands out: the ecosystem has undergone tremendous change since its origin several million years ago and, like ecosystems the world over, its rate of change is accelerating. The bosque, once a presumed mosaic of cottonwood-willow stands of different ages and isolation, was established by a meandering and periodically flooding Rio Grande. It was and still is greatly influenced by seasonal and longer-term climatic cycles. Currently it is a nearly continuous, linear mixture of native and introduced trees. Its native cottonwoods are in middle life and ageing faster than new individuals are being recruited.

Rates of change that brought the bosque to its current ecological state have grown more frequent and intense over the passage of geological and historical time. Between the early Pleistocene and the arrival of the Spaniards in the 1500s, the bosque's plant and animal communities underwent slow, climatically controlled shifts in distribution and abundance. Then, by introducing irrigation agriculture as well as exotic plants and animals, and by greatly exceeding the forest clearing practices of the valley's earlier Pueblo settlers, the Spanish colonists progressively constrained the distribution of the riparian forest.

More rapid and conclusive change, which for the first time severely impacted basin hydrology, resulted from the immigration of Anglo-Americans beginning in the middle of the 19th century. The combined effects of intensive lumbering, grazing and extirpation of the beaver in basin watersheds, together with the expansion of middle valley agriculture, decreased the capacity of watersheds to retain runoff water and, because of consequent erosion and sediment deposition, increased flooding and waterlogging in the floodplain. Meanwhile, diversion of upstream water for agriculture in Colorado reduced overall flows and caused the river below Albuquerque to frequently dry up, while intensified removal of cottonwoods and recurring drought added strain to the already stressed riparian communities along the river.

The river's hydrology, however, was most altered in the middle third of the 20th century, when floodplain drainage, irrigation improvement and river regulation were instituted. Whereas in the past its bosque communities were functionally connected to the river via overbank flooding, most are at present disconnected from their historical source of creation and maintenance: the now dammed, leveed and channel-straightened Rio Grande.

In this chapter we have attempted to describe the bosque's past and present ecology. Its future, which is receiving increased attention (Crawford et al. 1993, 1994, 1996), is now far more in the hands of humans than it was in the past.

Acknowledgements

We appreciate the willingness of Dan Scurlock to share his unpublished account of historical information with us, and thank Diane Rowland for reading the manuscript and for her thoughts on cottonwood root systems. Michelle Baker kindly drafted the illustrations. We also acknowledge the many contributions of our colleague Maury Valett to the way we think about riparian ecosystems. Phil Norton, John Taylor and other Bosque del Apache National Wildlife Refuge personnel are thanked for providing access to study sites and for their general support. Many others have contributed to various aspects of our research; we thank them all for their dedication and hard work. Funding for our research was provided by the U.S. Fish and Wildlife Service and the National Science Foundation.

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