The Lower Colorado River: A Western System[1]

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Abstract.--A historic look at the Colorado River will illustrate the drastic effects of human activity on most Western rivers. Engineering features for the management of water and electric power have resulted in increased evaporation, associated salinity, and other physicochemical changes; drastic reduction in many native plant and animal populations; increasing populations of introduced species; and changes in erosional and sedimentation rates.

"On the map the Delta was bisected by the river, but in fact the river was nowhere and everywhere, for he could not decide which of a hundred green lagoons offered the most pleasant and least speedy path to the Gulf. So he traveled them all, and so did we. He divided and rejoined, he twisted and turned, he meandered in awesome jungles, he all but ran in circles, he dallied with lovely groves, he got lost and was glad of it, and so were we." -Aldo Leopold in "A Sand County Almanac." (1949).[3]

"It has withstood man's attacks longer than James Ohio Patie's Hee-lay, (Gila) but in its function and even in its form, it is fast becoming a ditch. Dammed, artifically fed, stripped of its vegetation, its flow regulated, its wildlife depleted, the Verde is not merely tamed and domesticated, it is broken and emasculated - not yet dead but mechanically lifeless, an uncomplaining servant, dutifully obedient to its master." -James W. Byrkit in "A Log of the Verde." (1978).

INTRODUCTION

Riparian habitats in the arid Southwest are widely scattered but highly visible. The ephemeral, intermittent, and permanent streams of this region commonly flow through semiarid to arid terrain whose annual precipitation varies from less than 3 inches to more than 15 inches. Evaporation rates may approach, or even exceed, 100 inches each year. Even when Southwestern streams flow through relatively mesic areas the species of plants which constitute riparian communities usually differ sufficiently from the surrounding uplands to be obvious from a nearby prominence, an airplane or even on a high altitude photo. When compared to the drier surrounding uplands, these riparian wetlands with their lush vegetation are attractive oases to wildlife and humans alike.

In the recent Southwest as well as throughout recorded world history, and even prehistory, man has at least indirectly acknowledged the importance of riverine systems through transportation, settlement, and use patterns. These riverine systems have been widely used for exploratory routes; hunting, fishing and fur trapping; settlements, forts and cattle operations and, finally, extensive agricultural and urban developments. In spite of all this, riparian communities continue to be among the most neglected and poorly understood entities within the vast array of North American ecosystems. Even though the early explorers and settlers knew that they could more easily find plants and animals along streams to provide food, fuel, clothing, and shelter, there was basically no attempt to document and quantify species richness and population densities in these premium riparian habitats until the 1960s (Table 1). In spite of the fact that riparian avifaunas have now been examined for these factors, other vertebrates populations are still poorly understood while riparian invertebrate ecology is essentially unknown.

In the lower Colorado drainage, a general correlation exists between elevation and the dependency of birds on riparian, marsh, and

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[3] From an account of Leopold's visit to the Delta of the Colorado in 1922.

Table 1.--A comparision of breeding bird densities in selected habitats.
(After Johnson et al. 1977)

Habitat Type	Locality	Authority	Estimated Pairs/100 Acres nonriparian	riparian
Alpine Tundra				
Spruce-Fir Timberline	Wyoming	Finzel (1964)	15-17	-
Conifer Forest				
Spruce-Alpine Fir	Arizona	Carothers et al. (1973)	170-187	-
Fir, Pine, Aspen	Arizona	Haldeman et al. (1973)	253	-
Pine-Aspen Sagebrush Grassland	Wyoming	Finzel (1964)	18-30	-
Pine	Louisiana & E.Texas	Dickson (1978)	120-146	-
Spruce-Douglas Fir	Arizona	Balda (1967)[6]	380	-
Ponderosa Pine	Arizona	Balda (1967)	336	-
Ponderosa Pine	Arizona	Haldeman et al. (1973)	232	-
Relict Conifer Forest[1]				
Cypress post climax	Arizona	Johnston & Carothers (Ms.)	93	-
Riparian Deciduous Forest				
Mixed Broadleaf	Arizona	Balda (1967)	-	304
Mixed Broadleaf	Arizona	Carothers et al. (1974)	-	332
Cottonwood	Arizona	Carothers & Johnson (1975a)		1059[3]
Cottonwood	Arizona	Ohmart & Stamp (no date)[2]	-	683
Temperate Woodland				
Pinyon-Juniper	Arizona	Hering (1957)	33	-
Pinyon-Juniper	Arizona	Beidleman (1960)	30	-
Encinal (Oak)	Arizona	Balda (1967)	224	-
Subtropical Woodland (Bosque)				
Sonoran Desert Mesquite	Arizona	Gavin and Sowls (1975)	-	476[4]
Chihuahuan Desert Mesquite	New Mexico	King (1976)	-	756
Eastern Temperate Forest				
Pine-Hardwood	Louisiana & E. Texas	Dickson (1978)	143	-
Mature Deciduous	W. Virginia	Audubon F.N. (1948)	362[5]	-
Virgin Spruce	W. Virginia	Audubon F.N. (1948)	381	-
Eastern Bottomland Hardwoods				
Tupelo Swamp	Louisiana & E.Texas	Dickson (1978)	-	592
Oak-Gum	Louisiana & E.Texas	Dickson (1978)	-	301-346
Grassland				
Temperate Grassland	Arizona	Balda (1967)	64	-
Short Grass Prairie	Wyoming	Finzel (1964)	99-115	-
Yucca/Grassland	Arizona	Balda (1967)	31	-
Desert Scrub				
Chihuahuan Creosotebush	New Mexico	Raitt and Maze (1968)	9-18	-
Sonoran Paloverde/Sahuaro	Arizona	Tomoff(1974 & pers.comm.)	105-150	-
Mohave Mesquite Dunes	Nevada	Austin (1970)	6-11	-
Temperate Marshland				
Cattail Marsh	Arizona	Carothers & Johnson (1975b)	-	175-176
Marsh	California-Arizona	Anderson & Ohmart (1976)	-	215-283
Cultivated, Urban & Suburban Lands				
Urban (Artificial riparian)	Arizona	Emlen (1974)	-	615[5]
Cottonwood	Arizona	Carothers & Johnson (1975a)	-	605.2[3]

1 Arizona vegetation types after Brown and Lowe (1974).

2 Ohmart, R.D. and N. Stamp. No date. Final report on the field studies of the nongame birds and small mammals of the proposed Orme Dam site. Bur. of Recl. Proj., Boulder City, Ariz. 54 Ms. p.

3 Riparian cottonwood habitat disturbed by urganization. Two years prior, when the habitat was undisturbed, the density was 1058.8 pairs/100 acres.

4 Average density for April and May, the height of breeding activity in the mesquite bosque.

5 Density given in number of adult birds per 40 hectares (100 acres) instead of males or nesting pairs by Welty (1962) and divided by 2 for this table.

6 Balda, R. P. 1967. Ecological relationships of the breeding birds of the Chiricahua Mountains, Arizona. Ph. D. dissertation, Univ. of Illinois, Champaigne - Urbana.

7 King, H. T. 1976. Bird abundance and habitat in a southern New Mexico bosque. Masters thesis, N. Mex. St. Univ., Los Cruces.

other types of wetlands. Although Southwestern riparian habitats at higher elevations are important, the general rule is that the lower the elevation the larger the percentage of nesting avian species that are partially or entirely dependent on riverine ecosystems (Table 2). Water is apparently the limiting factor which determines this phenomenon.

From the small amount of information available there seems to be a contrast in the level of importance between the riverine riparian habitat of the Southwest and the more mesic habitats to the north and east. Some avian studies in the eastern forests suggest that bottomland hardwoods and/or swamp forests may support a greater avian species richness and population density than the surrounding uplands (Dickson 1978). However, the little avifaunal information available suggests that the magnitude of differences between the eastern riparian wetlands and the adjacent uplands may be almost as great as for southwestern situations in some instances but not in all. Further studies are needed to clarify this issue as well as to provide other important information regarding riparian ecosystems in general.

The objectives of this paper are threefold: (1) to discuss management problems in respect to the importance of arid land riparian habitats to wildlife, recreational and aesthetic

Table 2.--Numbers of avian species regularly breeding in selected areas of the Southwest with percentages of birds based on nesting habitat.

AREAS	WETLANDS (LAKES, MARSHES)	WETLANDS & OBLIGATE RIPARIAN	OBLIGATE RIPARIAN	PREFERENTIAL RIPARIAN	SUBURBAN AND AGRICULTURAL	NON-RIPARIAN	TOTAL SPECIES
Blue Point Cottonwoods [1]	-	10(17%)	16(28%)	17(29%)	1(2%)	14(24%)	58 *
Salt River Valley [2]	-	14(16%)	24(28%)	20(23%)	5(6%)	23(27%)	86
Central Arizona Mountains [3]	-	-	7 (7%)	22(22%)	3(3%)	70(68%)	102
Flagstaff [4]	6(5%)	9 (7%)	8 (6%)	22(18%)	2(2%)	78(62%)	125
Grand Canyon [5]	-	4 (3%)	16(13%)	17(14%)	2(2%)	83(68%)	122
Arizona [6]	8(3%)	23(10%)	41(17%)	52(22%)	6(2%)	112(46%)	242
Southwest Lowlands [7]	4(2%)	31(19%)	43(26%)	43(26%)	6(4%)	39(23%)	166

1. Simpson, J. M. & R. R. Johnson. Ms. History and ecology of the avifauna of Blue Point Cottonwoods, Maricopa County, Arizona.
2. Johnson, R. R., J. M. Simpson and J. R. Werner. Ms. History and ecology of the avifauna of the Salt River Valley, Arizona.
3. Reynolds & Johnson 1964; Johnson, R. R. [1970-72] The effect of chaparral modification on breeding song bird populations in Sycamore Canyon and Brushy Basin, Tonto National Forest, Arizona. Annual Rpts. to Rocky Mt. For. & Range Exp. Stn., Tempe; and R. R. Johnson field notes, Bradshaw Mountains, 1968-1977.
4. Carothers, S. W., R. P. Balda & J. E. Hildebrand. 1970. A checklist of the birds of Flagstaff, Arizona. Mus. of N. Ariz., Flagstaff, 4 p. field checklist.
5. Brown et al. 1978; field notes, NPS files, Grand Canyon National Park.
6. Phillips et al. 1964 and R. R. Johnson field notes.
7. Johnson et al. 1977 and R. R. Johnson field notes.

* 6 additional species have nested at least once, including the Bald Eagle.

values; (2) to review the extent to which past and current land and water management practices were, and are, modifying native riparian ecosystems in the Lower Colorado Basin; and (3) to discuss the maintenance and preservation of "second growth" riparian vegetation which we shall call a "reclamation disclimax." It should be a foregone conclusion that as land managers and scientists we must strive to understand and protect the scanty remnants of native riparian habitats. However, with a few exceptions, there has been little concern for the second growth riparian vegetation that has reinvaded modified drainages. Most of the concern for this new riparian habitat type has been from game management agencies such as the Arizona Game & Fish Department and others interested in the non-native saltcedar, especially as nesting habitat for Mourning (Zenaida macroura) and White-winged Doves (Z. asiatica). We shall further discuss the importance of this riparian type in both the Grand Canyon and Salt River Valley sections of this paper.

The Grand Canyon and the Salt River Valley are the two areas which have been selected to illustrate different effects of human activities on riparian ecosystems in the Lower Colorado drainage. The Colorado River in Grand Canyon is still the most nearly "natural" remaining segment of the mainstream of the Colorado River in the Lower Basin, despite the occurrence of Glen Canyon Dam only 16 miles upstream. By contrast, the Gila-Salt-Verde drainage has been so greatly altered that approximately half of their combined lengths is now dry.

GENERAL CHARACTERISTICS

The Colorado originates in the Front Range of the Rocky Mountains on the west side of the Continental Divide in the vicinity of Rocky Mountain National Park in Grand County, Colorado. Flowing southwesterly for 1,360 miles, the river leaves the United States, entering Mexico where it flows another 80 miles before entering the Gulf of California. Now, after almost a century of management of this drainage system, little water flows into the Gulf through the large, nearly dry delta. Although the Rio Grande, the only other major Southwest river, is longer by almost 400 miles, the Colorado drains approximately 245,000 square miles compared to only 170,000 for the Rio Grande. Major rivers in the Upper Basin include the Green, Gunnison, and San Juan while the Lower Basin is mainly drained by the Little Colorado and Gila. A number of smaller, tertiary rivers, usually a couple of hundred miles long and of great importance locally, are found in both the Upper and Lower Basins. In addition, a group of these tertiary rivers contributes to the drainage of the Gila Basin. The Gila, Salt, Verde, and Agua Fria are of special interest because they have been dammed to form storage reservoirs for irrigation and power production. A map of Arizona's perennial streams has been published by Brown et al. (1978).

Political and management considerations have resulted in the dividing of the Colorado into two regions. A point near Lees Ferry, 687.2 miles upstream from the international boundary with Mexico marks the division between the Upper Basin and the Lower Basin. The Upper Basin includes approximately 110,000 square miles of Wyoming, Utah, Colorado, and New Mexico while the Lower Basin drains approximately 135,000 square miles in Utah, Arizona, and New Mexico. In addition portions of California and Nevada are included in the Lower Basin but no major rivers flow into the Colorado River from those states.

Several natural areas along the Colorado and its tributaries are important enough to have been set aside by the National Park Service. In the Upper Basin, these include the aforementioned Rocky Mountain National Park as well as Arches National Park, Capital Reef National Park, Canyonlands National Park, Natural Bridges National Monument, and Dinosaur National Monument. Approximately two dozen National Forests are found throughout the Colorado River Basin. "Preserves" located along the Colorado and its tributaries include the Cibola, Havasu, and Imperial National Wildlife Refuges which are administrated by the United States Fish and Wildlife Service. Indian reservations range in size from the Navajo Reservation, the largest southwestern Indian Nation, (more than 20,000 square miles) to the Yuma and Gila Bend Indian Reservations of only a few square miles each. With the formation of large storage reservoirs along the river system, recreational areas have been established under the jurisdiction of the National Park Service. In the Upper Basin these include Flaming Gorge National Recreation Area on the Green River and Glen Canyon National Recreation Area on the Colorado, while Lake Mead National Recreation Area has been established on the Colorado in the Lower Basin.

In addition to natural areas, e.g. Grand Canyon National Park and Zion National Park, many areas have been set aside because of their archeological importance. Prehistoric Indians commonly settled along streams, sometimes building fortified sites on cliffs and promontories while farming in the nearby floodplains. These national monuments include Gila Cliff Dwellings in New Mexico; and Tuzigoot, Montezuma Castle and Well, Tonto Cliff Dwellings and others in Arizona.

A variety of vegetation types and biotic areas occur between the Colorado's headwaters and its mouth as it flows from glaciated elevations in excess of 14,000 feet at the top of the Rocky Mountains, southwest across the Colorado Plateau, then south through arid deserts to the Gulf of Lower California. In addition, elevations within the Basin descend to almost 250 feet below sea level at the Salton Sea.

Riparian and upland vegetation types along the river and adjacent areas include all of the major formations listed by Brown & Lowe (1974): Tundra, Forest, Woodland, Scrubland, Grassland, Desertscrub, and Marshland. The woody vegetation along the Colorado River bottom varies from willows (Salix spp.) and alders (Alnus spp.) at higher elevations through cottonwoods (Populus spp.), willows and saltcedar (Tamarix chinensis) at intermediate elevations to (Baccharis), arrow-weed (Pluchea sericea), saltcedar, mesquite (Prosopis spp.) and cottonwood-willows at lower elevations.

A recent map published by Brown et al. (1978) includes these types: Rocky Mountain, Great Basin, Mohave, and Sonoran Desert. Riparian vegetation includes Rocky Mountain Alpine Scrub, mostly dwarf willows; Rocky Mountain Deciduous Scrub, Willow-Alder Series; Southwestern (Riparian) Deciduous Forest and Woodland, Cottonwood Willow Series and Mixed Broadleaf Series; Interior Southwestern Riparian Scrub, Broom and Seep-Willow Series (Baccharis spp.) and Saltcedar Series; Sonoran Riparian Deciduous woodland, Mesquite Series; and Sonoran Riparian Scrub, Mixed Scrub Series, Arrow-weed Series, and Saltcedar Series.

To determine the flora and fauna occurring along various segments of the Colorado River, one must consult the various state and local publications regarding these subjects. In addition, floral and faunal lists have been compiled by many of the aforementioned parks, forests, etc. The riparian vegetation of the Grand Canyon has been mapped by researchers at the Museum of Northern Arizona (Phillips and Phillips unpubl.) and portions of the Lower Colorado by Anderson and Ohmart (Bur. of Reclam., Boulder City, Nev.).

THE COLORADO RIVER IN GRAND CANYON

The Colorado ranks as a third class river, at best, when comparing the natural attributes of great rivers of the world. However, the best known natural feature of the Colorado River drainage, the Grand Canyon, is considered one of the natural wonders of the world. This spectacular canyon is 277 miles long, 13 miles at its widest and more than 1 mile deep at its deepest. The Precambrian schist and granite at its bottom, at 3 billion years of age (Breed and Roat 1976), are among the oldest known rocks on earth. The Grand Canyon has been shown by recent international surveys to be the most popular natural tourist attraction in the United States (various new reports). Hunt (1967) when discussing the geology of the Colorado Plateau mentions Grand Canyon and the Painted Desert as features which contribute to this region as being "easily the most colorful part of the United States."

Although the Colorado was discovered by Hernando de Alarcon in 1540, it was not until 1869 that the 277 mile segment flowing through the Grand Canyon was explored (Powell 1875). One of the better recent anthologies regarding the Grand Canyon is by Babbitt (1978). Although geological interest in this region developed early, it was not until the close of the century that any notable biological exploration was conducted. It was then that Merriam (1890) developed his noted Life Zone concept during investigations conducted from the top of the San Francisco Peaks (12,670 feet) to the bottom of the Grand Canyon (less than 3,000 feet elevation). All of Merriam's Life Zones, from Arctic-Alpine through Lower Sonoran, are well represented along the Colorado River. In addition to the aforementioned information regarding vegetation mapping of the Grand Canyon, Carothers and Aitchison (1976) compiled a floral and faunal list for the riparian zone along the Colorado River in Grand Canyon.

Although Grand Canyon National Park was established in 1919, a thorough inventory of the vertebrates of the region has not been undertaken until recently. The fishes of the Colorado River within the park include 15 introduced and 4 native species (Minckley and Blinn 1976; Suttkus et al. 1976). Tomko (1975) published a list of the amphibians and reptiles and Brown et al. (1978) have just published an annotated checklist of the birds of the region. Hoffmeister (1971) published a book on the mammals and supplemental information has been published by Ruffner et al. (1978) and Suttkus et al. (1978). In addition, field checklists of the terrestrial vertebrates are available from the Natural History Association at Grand Canyon.

New Riparian Habitat "Reclamation Disclimax"

The major reason for our interest in the Colorado River in Grand Canyon is to examine the factors related to newly established riparian habitat. The completion of Glen Canyon Dam in 1963 resulted in environmental changes which were devastating to several fishes listed as threatened or endangered by the U.S. Fish and Wildlife Service (1973 and supplements published periodically in the Federal Register). Notable examples are the chubs (Gila spp., see Suttkus and Clemmer 1977). On the other hand, some of the post-dam changes in water regimes have been conducive to the establishment of riparian scrub composed mainly of sandbar willow (Salix exigua), saltcedar, arrow-weed and seep-willows. In the rest of the Lower Colorado Basin, there has been a drastic reduction in the total amount of riparian habitat. Further, the little remaining habitat is generally in poor condition due to several factors including: (1) reduction in surface and groundwater; (2) grazing and consequent lack of regeneration; (3) invasion by non-native species, e.g. saltcedar. Ffolliott and Thorud (1974) estimated that less than 1/2 of 1% of the total habitat in Arizona was riparian. Thus, the establishment of riparian habitat in the Grand Canyon is of major interest (Carothers et al., in press).

With the increase in riparian vegetation there has been a (re)invasion by several avian species, such as Bell's Vireo (Vireo bellii), Hooded Oriole (Icterus cucullatus), and Summer Tanager (Piranga rubra) (Brown et al. 1978) as well as an apparent increase in population densities for species such as Lucy's Warbler (Vermivora luciae), Yellow Warbler (Dendroica petechia) and Common Yellowthroat (Geothlypis trichas). It is difficult to determine the magnitude of these changes since no pre-dam surveys of the area were conducted. Factors leading to these changes include: (1) reduction in flood levels from up to 300,000 cfs. (Dolan et al. 1974) before construction of the dam to post-dam maximum flows of between 30,000 and 50,000 cfs, and; (2) a more constant water supply. Pre-dam photos (NPS files) show that vegetation was scoured from the river's banks by these periodic floods. The Colorado now acts like a tidal river with daily fluctuations in water levels determined by water releases related to power generation at Glen Canyon Dam.

The daily tidal fluctuations of the river through providing a more constant source of water for the establishment of riparian vegetation on the terraces ("beaches") at the river's edge, have proven to be a mixed blessing. When coupled with the erosional force of the low silt bearing water which now flows through Grand Canyon, the result is a reduction in size of many of these terraces which bear riparian vegetation (Dolan et al. 1977). In addition, plans for the modification of Glen Canyon Dam to allow releases well in excess of 50,000 cfs (up to 100,000 cfs?) are currently being considered by the Bureau of Reclamation (pers. comm.). Thus, the fate of this newly established riparian habitat is questionable.

WATER STORAGE AND THE SALT RIVER VALLEY

Although the Colorado River is not one of the major rivers of the world, it and its tributaries have been important to humans for thousands of years. This has not changed with modern technology, and, in fact, is now even more important. Construction of gigantic irrigation and power projects have converted almost all rivers in the Lower Basin into a series of reservoirs behind dams, alternating with controlled flows (regulated water released from dams) and dry river beds. Perhaps no river in the United States has been more highly used and modified. Several hundred engineering structures have modified the Upper Basin rivers while more than a dozen large dams have been built on the rivers of the Lower Basin. In addition to storage and diversion dams for power and irrigation, other engineering features include tunnels, dikes and levees, riprapped banks, canals, pipelines, pumping plants, substations, and transmission lines.

Early Irrigation

A discussion of the Verde-Salt-Gila River system will illustrate the extent to which rivers in this region have been modified. This extensive system formerly consisted of three naturally perennial streams and several permanent tributaries which drained central and southern Arizona, and central western New Mexico. Today, less than half of the more than 1,000 miles of river are not impeded by major dams. Even along this half are located diversion structures for local irrigation projects, mining and other uses. The remaining half of the system consists of dry stream bed and more than 100 miles of storage reservoirs and large diversion structures. Most of the water storage programs are conducted by the Salt River Project to provide power and water for Phoenix and the rest of the Salt River Valley.

An examination of the history and prehistory of the Salt River Valley, thus, provides an excellent case study of agricultural and rural development in a river valley. This valley knew continous and successful habitation from at least 200 years B.C. through 1400 A.D. The Hohokam, considered by authorities to be ancestors of the Pimas and/or Papagos, irrigated and farmed the valley, leading what Haury (1967) called a "peaceful and prosperous life." Using stone axes and hoes, they diverted the water of the Salt and Gila Rivers into their corn and cotton fields. It has been estimated that during that time the valley supported a larger rural population than it does today, with small family units and villages situated along the many canals (Haury 1967). Most of today's inhabitants of the Salt River Valley live in Phoenix and its suburbs.

Historically, agricultural development was reintroduced when Jack Swilling began the Swilling Irrigation Canal Company in 1867. His inspiration rested on the understanding that the ancient earthworks in the area had once served the vanished Indian communities. Thus, after 500 years of inactivity, water was once again diverted from the Salt River and flowed through earthen ditches. The irrigation project developed quickly, growing from 100 people and 250 acres in the fall of 1868 to 8,000 acres in 1872. Crops consisted of oranges, grapes, figs, and walnuts. In addition, wheat and alfalfa were grown largely to feed cavalary animals at Ft. McDowell on the Verde River near its confluence with the Salt River just east of Phoenix (Salt River Project 1970). By 1888 a half dozen major canals served the Salt River Valley (Salt River Project, no date a) and by 1982, 107,118 acres were under irrigation (Arizona Republic May 18, 1969).

Reclamation and The Salt River Project

With the expansion of population and the growth of human related activities in the valley, it became inevitable that the possibility of water storage be investigated. Valley farmers, in response to seasonal and yearly variations in weather which they called "drought" were constantly demanding more water. Uneven water distribution, conflicts of interest and legal wrangling over water rights complicated the issues. In 1889, Senator W. M. Stewart of Nevada visited western states to discuss dam sites with local citizens. The Maricopa Board of Supervisors investigated various sites and provisionally selected the Tonto Basin, at the confluence of Tonto Creek with the Salt River. The money for dam construction had to wait for President Theodore Roosevelt's signing of the National Reclamation Act in 1902. The estimated cost was $2,700,000. Costs spiraled and by 1917 the amount was figured at $10,166,000, increasing the cost to shareholders from the original $15 an acre to $60 an acre (Salt River Project, no date a). This loan was repaid in October 1955. The finished dam was dedicated in March of 1911 by President Roosevelt. It was the world's highest masonary dam, having a storage capacity of 1,381,580 acre feet of water (Salt River Project, no date b). From a beginning population of 100 Anglo settlers in 1868, the Salt River Valley has grown to a complex urban, suburban, and rural development. Today, metropolitan Phoenix has a population of approximately 690,000 people with approximately 1,000,000 people residing in the Salt River Valley. To provide water and power for an ever growing population, waters were diverted from the Salt and Verde River systems finally resulting in the Salt becoming dry from Granite Reef diversion dam downstream to its confluence with the Gila. The Verde River has continued to flow to its confluence with the Salt below Horseshoe and Bartlett Dams except when this flow is turned off at Bartlett Dam. In addition, the Gila was "turned off" by the completion of Coolidge Dam (San Carlos Lake) in 1929 and is dry from that dam downstream to its confluence with the Salt and from there west to the Colorado (Dobyns 1978).

Effects of Irrigation on Birds

As was mentioned previously, the lack of early biological records make it difficult to determine the rates and magnitude of ecological changes which accompanied these drastic modifications of the stream systems. Most of our discussions regarding these changes will center on the avifauna. In monitoring the "biological health" of an area we find birds to be a better "thermometer" than other terrestrial vertebrates for several reasons. The first reason is practicality. Most birds are relatively easy to find and observe because they are diurnal and fly. In addition, they sing during the breeding season, allowing one to estimate population numbers. Contrast these characteristics with other non-aquatic vertebrates such as most reptiles and mammals which are nocturnal and/or spend much of their time hidden from view. In addition, disturbed areas which are recovering from ecological damage are more rapidly recolonized by these winged vertebrates than by other terrestrial species. We know of no definitive publication concerning the ecological changes which occurred during the first century of irrigation in the Salt River Valley. Some of the qualitative changes have been discussed orally by Johnson (1972). Thus, we can only piece together information from scattered sources such as from a 1907 egg collecting expedition by oologists. (Hanranft 1908) reports collecting eggs of several species from cottonwood trees in irrigated areas west of Phoenix along the Agua Fria River. Included in the collection were eggs of the Vermillion Flycatcher (*Pyrocephalus rubinus*) and Baird's (Ladder-backed) Woodpecked (*Dendrocopos scalaris*). In Phoenix and vicinity today, both these species are found in small numbers in riparian habitat. The closest nesting Vermillion Flycatchers occur in very limited numbers along the Salt and Verde Rivers, approximately 50 miles east of where these early collectors worked.

During this century several basic changes have occurred in the avifauna of this area. As the rivers became increasingly dry, riparian and aquatic plants and animals diminished in number and distribution along the river courses. However, much of the surrounding desert was replaced with relatively primitive irrigation systems consisting of fields and tree lined earthen ditches. These ditches simulated small streams and provided habitat for many species of fish, amphibians and other wetland species of animals as well as plants. The trees, shrubs and accompanying vegetation along the ditches provided man-created riparian habitat for 20 to 30 species of nesting birds while pasture and field crops provided nesting sites for several additional species. Small diversified farms which combined the raising of livestock and poultry with a variety of crops resulted in the maintenance of a diverse biota of native species.

With the loss of the native cottonwood-willow forests and mesquite bosques along the Salt and Gila during the first part of the century, many riparian nesting species could not adapt to the new, arid conditions. These included the Ferruginous Owl (Glaucidium brasilianum), Yellow-billed Cuckoo (Coccyzus americanus), Summer Tanager (Piranga rubra) and many others. Some species such as the Gila Woodpecker (Melanerpes uropygialis), Black Phoebe (Sayornis nigricans) and Crested Flycatcher (Myiarchus tyrannulus) adapted well to this new "artificial" riparian habitat around farms and ditches.

In the mid-1900s farming methods changed drastically. Trees were cut down and ditches cemented to reduce water losses from evapotranspiration and percolation. Waste areas along ditches and fence rows which provided food and cover for wildlife were eliminated to produce more acres of cotton and alfalfa. "Clean farming" methods consisted of mass use of herbicides and insecticides. Books, scientific papers, articles, and television shows have widely discussed the direct effects of farm chemicals on wildlife; the indirect effects of loss of food and cover have also been devastating. In one locality near Peoria seven species had ceased to breed by the late 1950s and early 1960s while only three new species had started to nest in the area. The three new species are the Curve-billed Thrasher (Toxostoma curvirostre), the Common Starling (Sturnus vulgaris) (a European introduction) and the Great-tailed Grackle (Quiscalus mexicanus), which has recently extended its range northward from Mexico (Phillips et al. 1964). The last two are closely associated with human activity.

It is difficult to determine which factor or combination of factors has been critical in the loss of any given species in part of its range. In the Salt River Valley, the reduction in populations of many avian species and the complete loss of others has resulted from any one of several different factors or a combination of these factors. These include: loss or disruption of native riparian habitat, cementing of canals and ditches, destruction of trees and other plants along canals and ditches, "clean farming" practices and loss of fence rows and "waste" areas, widespread use of insecticides and other agricultural chemicals and, finally, urbanization.

BIOLOGICAL INVESTIGATIONS IN RIPARIAN HABITAT

Despite the acknowledged importance of river systems to prehistoric, early historic and technologic man, our knowledge of the biological composition of riparian ecosystems, when European man settled the United States is basically non-existent. Early explorers were usually laymen, army officers or scientists (e.g. geologists) who had only scant knowledge of the biota and left poor to incomplete biological records. Even when biologists accompanied exploration parties, they could not even record all of the descriptive information they observed. They often encountered plants and animals which were either poorly known or unknown, such as the Abert's Towhee (Pipilo aberti) which was not known to science until 1852 (AOU 1957), or even more obscure animals such as the humpback chub (Gila cypha) which would not be described until later in the 20th Century (Miller 1946). Early records from rivers such as the Colorado (Emory 1848), and the Gila commonly mention wildlife and vegetation only in general terms. Therefore, when attempts are made to reconstruct the riparian conditions of a river even as relatively well known as the Colorado (Ohmart et al. 1977) a great amount of extrapolation is necessary. Thus, only partial lists of riparian tree species for the Lower Colorado Drainage and to a lesser degree, shrubs, can sometimes be reconstructed from notes left by these biologists during the late 1800s and early 1900s. The prevalent upland game species, waterfowl, furbearers and predators, as well as other general faunal components, were sometimes enumerated. However, herbaceous plants, small vertebrates, nongame wildlife, and invertebrates (other than mosquitoes) were seldom discussed. Information regarding population densities and other quantitative data was not even mentioned.

Ecotones, Edge Effect and Ecological Diversity

The edge effect increases the complexity of the study of riparian habitats. This concept has been only recently developed for it was not until the mid-1900s that the implications of this phenomena were well enough understood to be discussed by ecology texts (see Johnson et al. 1977). Odum (1959) defines the edge effect as "the tendency for increased variety and density at community junctions." One of the first ecologists to deal with the edge effect was Aldo Leopold (1933). He defined the term and emphasized that all of the reasons for the phenomenon were not understood. It is interesting that in a recent paper on the edge effect Thomas et al. (1978) quoted from Leopold's work but inserted the word "wildlife" to illustrate that these principles apply to wildlife in general and not just game animals. In an earlier publication Carothers and Johnson (1975a) discussed the confusion of the term game management with wildlife management. Some resource management agencies continue to promote game management under the guise of general wildlife management.

Thomas et al. (1978) list two basic types of edges, inherent, and induced. Inherent edges are due to long-term factors such as soil or exposure while induced edges result from short-term factors such as fire or flooding. An inherent edge may be either abrupt or a mosaic. An abrupt edge occurs where environmental conditions result in a relatively sharp junction between two basic habitat types. A mosaic edge has more total edge area than the abrupt type and thus should display a greater total diversity.

Others have noted the increased species richness associated with riparian ecosystems. In California, Miller (1951) although not pointing out the edge effect, stated "the number of species of birds associated with riparian woodland is larger than that of any other formation." Other papers in this symposium document the fact that these California riparian ecosystems have also experienced drastic reductions in wildlife, recreational and aesthetic values.

Another factor related to the edge effect which increases the ecological diversity, and therefore complexity, of these ecosystems is the allied concept of ecotones. Riparian habitats may be considered ecotones between the aquatic habitat of the stream itself and the surrounding terrestrial habitats. As such, the riparian ecosystem contains elements of both the aquatic and terrestrial ecosystems plus retaining unique characteristics not found in those two ecosystems. Care must be taken when dealing with ecotones and the edge effect. Arnold (1972) suggested that removing trees from dense riparian groves would produce clearings which should improve wildlife habitat values. Conversely, Carothers and Johnson (1975a) found that reduction in the number of mature cottonwoods in riparian groves in the Verde Valley of central Arizona resulted in nearly a straight line relationship to reduction in avian populations.

MANIPULATION OF RIPARIAN VEGETATION AND ITS EFFECTS ON AVIAN POPULATIONS

Even in ornithology, the best known of riparian studies, one is fortunate to find a complete list of avian species for either extant or extirpated stream systems. The extremely high densities of riparian avian populations in general was not recognized until this decade (Carothers et al, 1974, Carothers and Johnson 1975b, Hubbard 1977, Johnson and Jones 1977, Johnson 1970, Sands 1977, and Table 1). Although most of the references in this section refer to breeding birds similar findings pertain to transients. Rappole and Warner (1976) found that migrating birds showed a decided preference for riparian habitat and expressed the same concern for these birds that are commonly expressed for breeding and wintering birds. Stevens et al. (1977) found that censuses in riparian habitat commonly resulted in several times the number of migrants when compared to adjacent upland habitat. Thus, destruction of large tracts of choice riparian habitat may effectively interrupt migratory routes and cause excessive losses to migrating species which could have the same deleterious effects as destruction of nesting habitat.

In 1956 a landmark report discussed the possibilities of increased water yield by vegetation management on Southwestern watersheds. This report, commonly called the "Barr Report" (Barr 1956), was at least partially instrumental in establishing programs that were to be carried on into the 1970s. Juniper, brush and other vegetation control projects were often promoted as multiple use projects by government agencies and private "water salvage" organizations. The value of the techniques in restoring range for cattle and wildlife was widely advertised but the underlying cause was always increased water yield.

A more recent report (Ffolliott & Thorud 1974) estimated possible increases in water yields under various levels of vegetation removal in Arizona. This report was not as widely accepted as Barr's since recent benefit-cost studies have demonstrated the financial infeasibility of many of the programs intended to increase water yields. Clary et al. (1974), for example, found that removal of southwestern pinyon-juniper was not likely to increase water yield, and value to cattle and game was questionable since only the more successful conversion projects just about break even from a benefit-cost standpoint.

Some non-riparian brush control projects may improve range habitat for birds (Carothers and Johnson 1975a). However, all management programs which alter riverine ecosystems that we have examined have been detrimental to avian populations with the single exception of the newly created reclamation disclimax in Grand Canyon, discussed earlier in this paper.

Detrimental projects include channelization (Carother & Johnson 1975b), phreatophyte control (Johnson 1970) and water storage projects which inundate riparian areas.

During the 1960s and early 1970s, several agencies were concerned with the loss of water through evapotransporation from phreatophytes. A special interagency organization, the Pacific Southwest Interagency Committee, was organized to examine methods of reducing these reported water losses. In 1966, a PSIAC symposium was conducted to discuss the general problem. One of the most commonly advocated methods, of course, was the removal of vegetation from stream courses. Some of the earlier projects concentrated on the removal of the non-native saltcedar. This soon led to the removal of native riparian species such as cottonwoods and willows.

In 1968 the Arizona State Water Resources Committee sponsored a symposium regarding phreatophyte clearing projects. Bristow presented one of the first papers to address the loss of wildlife habitat in these removal programs. Phreatophyte concerns were so extensive that Horton, a specialist on the systematics of saltcedar as well as various other phreatophyte subjects, compiled a bibliography covering the mass of literature which had accumulated (1973). However, sentiments supporting the philosophy of complete removal of phreatophytes was gradually changing and a year later Horton and Campbell (1974) published a paper on the multiple use values of phreatophytes which addressed, among other subjects, wildlife values. During the four ensuing years, the term "phreatophyte," with its unsavory connotation as a water waster, has become far less frequently used.

UNSOLVED PROBLEMS

A variety of unsolved problems continue to plague us. A few of these are briefly discussed here.

1. Over-allocation and unequitable distribution of water.-In Arizona 89% of water usage is for agriculture, leaving the remaining 11% for all other uses (Arizona Water Comm. 1977). Parenthetically, .8% is allocated to fish and wildlife. Figures for the rest of the arid west are similar. Demands for water so far exceed the supply that a total of 16.5 million acre feet annually have been allocated from the Colorado River despite annual flows averaging less than 14 million acre feet annually between 1922 and 1966 (Dracup 1977).

2. Erosional and other problems created by poorly conceived and designed diversion and irrigation structures.-Current resource management problems often stem from water control structures and use patterns. I shall relate three examples. The first is by Dobyns (1978) who wrote, "About 1883, farmers near Solomonville, irked when San Simon Creek freshets deposited sand, gravel, and other debris on their fields, dug ditches to divert creek waters past their fields. The creek promptly began to erode downward and headward, so that within a few years, a sixty-mile-long channel from ten to thirty feet deep gaped from 600 to 800 feet wide in the San Simon Valley, previously famous for artesian wells. Water dropped, in obedience to the law of gravity, below the floor of the new canyon."

In addressing this same basic problem Brandt (1951) had this to say; "The slender Santa Cruz River, at the point where it flows into the grand mesquite forest, evidently enters a wide level area. Meanwhile it seems to spread its intestine waters out underground in a deltalike fashion, which, due to an impervious substratum, seem to form a sort of subterranean sandy swamp with no water on the surface, but with apparently a broad, rich reservoir not too far below. In May, the river, as it formerly flowed through the forest, appeared and disappeared several times in its sandy bed and was often many channeled. This peculiar combination of natural conditions caused a sweet water level within reach of the long mesquite roots and, while the surface of the ground might have been perfectly dry, it evidently was well watered below, thus giving grateful nurture to the marvelous trees that were fostered there.

About 50 years ago, however, mankind with his destructive 'improvements' appeared. A prominent pioneer named Sam Hughes is said to have constructed the first irrigation ditch at the edge of Tucson. Floods quickly enlarged and deepened this ditch in to a minature gorge, cutting back in a few seasons to an artificial lake at the upper end of town. This deepened channel soon drained the lake and kept on eating its way back towards the forest. Flood waters seem to have extended the gorge with ever increasing speed and were helped in their destruction by other foolish irrigation ventures on up the valley until it reached the forest. The lowered drainage soon caused the sweet water level to drop many feet and when the moisture binder is taken from adobe desert soil the latter becomes finely powdered silt, which can resist but little the savage erosion of the torrential rains that only too frequently occur in that region. A deep channel, consequently, was cut out of the river bottom in the forest, leaving vertical silt bluffs in many places 20 to 40 feet high. Soon lateral grooved canyons developed until at the present day, the river bottom is a master canyon with numerous, hideous cleft affluents that are gnawing back into the forest and rapidly eating out its green heart. Aside from unwise irrigation ventures, the clearing of the bottom land of the larger tree growth south of the grand mesquite forest, which is up the valley, has been one of the main factors in contributing to the destructive erosion. The reason is that the primitive dense vegetation cover there held back the floods and gave time for much of the water to soak into the soil, permitting the rest to flow slowly down the valley."

Although Brandt was not a hydrologist or erosion specialist, his writing leads one to question the premise that vegetation removal ipso facto is effective in reducing flooding. Cooke and Reeves (1976), in addition to referring to the Santa Cruz Plains, state that, "It seems reasonable to conclude at present that the best hypothesis to explain arroyo formation along the major valley floors of southern Arizona acknowledges the possibility of increased valley-floor discharge due to climatic and/or vegetation changes but emphasizes the role of drainage concentration features and related changes along valley floors."

3. Excessive withdrawal of groundwater.-As early as 1936, Smith pointed out the dangers of lowering water tables, increasing the lift and consequently the costs of pumping water. In 1975 the Arizona Water Commission reported excessive annual withdrawals ranging from 1.8 feet for the Salt River Valley to 13.8 feet for the Harquahala Valley. In addition to eventually running out of water, recent land subsidence due to this excessive withdrawal has resulted in property damage and reduced land values.

4. Problems associated with storage projects. -Of particular concern are water losses from evaporation, and percolation into the bed of the reservoir, as well as increasing salinity. A desalting plant on the Colorado near Yuma will cost an estimated $200,000,000 to construct while operation is estimated at a cost in excess of $16,000,000 annually (USDI-BR 1977).

5. Grazing.-Problems such as a lack of regeneration of riparian vegetation and destruction to the understory are discussed in detail by other papers in this symposium.

6. Loss of native riparian habitat and invasion by non-natives.-Less than 1/2 of 1% of the land in Arizona bears riparian habitat. In Missouri, Korte and Fredrickson (1977) report that when European settlers arrived in the 1780's they found 2.4 million acres of lowland ("riparian") forest. The 98,000 acres remaining today constitute only 4.1% of the original acreage. Similar situations exist in much of the rest of the United States. Turner (1974) presented evidence that non-native "saltcedar can eliminate native riparian species such as cottonwood and seepwillow."

7. Extirpation or reduction in numbers of native animals.-The Endangered Species Act of 1973 deals with species in danger of extirpation. The most notable example of such a species on the lower Colorado is the Yuma Clapper Rail (Ohmart & Smith 1973). A more insidious problem exists in regard to the large percentage of species which are totally or partially dependent on riparian habitat during part or all of their life cycles (Table 2 and Johnson et al. 1977).

8. Problems inherent in manipulation of riverine environments and construction in flood plains.-Our greatest problems stem from settlement activities in floodplains. A subject of increasing concern is floodplain management (Kusler 1976) as loss of life and property in floodplains continue to mount. Rather than solving the problem, expensive flood control projects commonly merely move the problem downstream by channeling water downstream from one location to another. The only suitable answer to this problem is sound land use planning and floodplain management.

SUMMARY

Laws and policies designed to protect riparian values are still sadly inadequate. Cultural artifacts on public land have been protected since 1906 by the Antiquities Act (Lee 1970). Sixty-three years had passed before enough concern was generated to pass the National Environmental Policy Act of 1969, designed to protect the human environment, especially with regard to clean air and water. Four years later the Endangered Species Act of 1973 was passed in an attempt to prevent an ever-increasing number of species from going the way of the Passenger Pigeon and Carolina Parakeet.

As improved techniques facilitate the gathering of scientific information about riparian habitats and their complex and diverse ecosystems several facts become evident:

1. Most human activities along rivers have been detrimental to riparian ecosystems.

2. Better assessments are needed to fully determine the wildlife, recreational, and aesthetic values of these areas.

3. Riparian vegetation is more important than formerly realized in maintaining water quality, probably in the maintenance of clean air and possibly in affecting local climatic conditions.

4. In many, if not most, regions riparian habitats have been reduced to less than 10% of their original areas. Continued reduction of this critical water resource may shortly result in irreversible damage to its human as well as non-human values.

The importance of additional research and improved management in riparian habitats is unquestionable. However, even though better assessments of the values of these areas are needed an informative body of information is currently available. Thus, the greatest task ahead is the wise use of this information to formulate laws and policies for protecting and improving riparian habitats. This action is crucial in contributing to improving our quality of life today and in the future.

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LITERATURE CITED

American Ornithologists's Union. 1957. Checklist of North American birds. Fifth ed. A.O.U., Baltimore. xiii + 691 p.

Anderson, B. W., and R. D. Ohmart. 1976. Wildlife use and densities report of birds and mammals in the lower Colorado River Valley. USDI Bur. of Reclamation, Lower Colo. Region, xiv + 278 p.

Arizona Water Commission. 1975. Summary: Phase I: Arizona State water plan, inventory of resource and uses. Ariz. Water Comm., Phoenix, Ariz. 34 p.

Arizona Water Commission. 1977. Phase II: Arizona State water plan, alternative futures. Phoenix, Ariz. xiii + 145 p.

Arizona Water Resources Committee. 1968. Proceedings of the 12th annual Arizona watershed symposium. Watershed and Forestry Div. of Ariz. State Land Dept. 48 p.

Arnold, J. F. 1972. Ecology and management of riparian vegetation (abstract). Jour. Arizona Acad. Sci., Proc. Suppl. 20.

Austin, G. T. 1970. Breeding birds of desert riparian habitat in southern Nevada. Condor 72:431-436.

Babbitt, B. (Ed.) 1978. Grand Canyon: an anthology. Northland Press, Flagstaff, Ariz. xv + 258 p.

Barr, G. W. (Ed.) 1956. Recovering rainfall, Part I, Arizona watershed program. Coop. Proj. Ariz. State Land Dept., Water Div., Salt River Valley Water User's Assn., Univ. of Ariz. 33 p.

Beidleman, R. G. 1960. Breeding bird census. Pinyon pine-Rocky Mountain juniper forest. Audubon Field Notes 14:495-496.

Brandt, H. 1951. Arizona and its bird life. Bird Research Found., Cleveland, Ohio, xvi + 725 p.

Breed, W. J. and E. Roat (Eds.) 1976. Geology of the Grand Canyon. Museum of Northern Ariz., Flagstaff, and Grand Canyon Nat. Hist. Assn., Grand Canyon, Ariz. xiii + 186 p.

Brown, B. T., P. S. Bennett, S. W. Carothers, L. T. Haight, R. R. Johnson, & M. M. Riffey. 1978. Birds of the Grand Canyon region: an annotated checklist. Grand Canyon Nat. Hist. Assn., Grand Canyon, Arizona. 64 p.

Brown, D. E., N. B. Carmony, & R. M. Turner. 1978. Drainage maps of Arizona showing perennial streams and some important wetlands. Arizona Game and Fish Dept., Phoenix, 1:1,000,000 scale map and selected references and annotations.

Brown, D. E. and C. H. Lowe. 1974. A digitized computer compatible classification for natural and potential vegetation in the southwest with particular reference to Arizona. Ariz. Acad. Sci., Suppl. 2. 11 p.

Brown, D. E., C. H. Lowe, & C. P. Pase. 1977. Biotic communities of the southwest. USDA For. Serv. Gen. Tech. Rpt. RM-41, Ft. Collins, Colo. 1:1,000,000 scale map with 2 p. suppl. (cartographer: V. H. Booth).

Byrkit, J. W. 1978. A log of the Verde. Jour. of Arizona. Hist., 19:31-54.

Carothers, S. W. and S. W. Aitchison. 1976. An ecological survey of the riparian zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Colorado River Technical Report No. 10, Grand Canyon National Park, Arizona. 251 p.

Carothers, S. W., S. W. Aitchison, & R. R. Johnson. In press. Natural resources in Grand Canyon National Park and river management alternatives on the Colorado River. In Proc. First Conference on Scientific Research in the National Parks. USDI Natl. Park Serv., Wash., D.C.

Carothers, S. W., R. P. Balda, & J. R. Haldeman. 1973. Habitat selection and density of breeding birds of a coniferous forest in the White Mountains, Arizona. Mus. of N. Ariz., Tech. Bull. 12:22-54.

Carothers, S. W., R. R. Johnson & S. W. Aitchison. 1974. Population structure and social organization in southwestern riparian birds. Amer. Zool. 14:97-108.

Carothers, S. W. and R. R. Johnson. 1975a. Water management practices and their effects on nongame birds in range habitats. p. 210-222. In Smith, D. (Tech. Coord.); Proc. of Symp. on Management of Forest and Range Habitats for Nongame birds. USDA For. Serv. Gen. Tech. Rpt. No. 1. Wash., D.C.

Carothers, S. W. and R. R. Johnson. 1975b. The effects of stream channel modification on birds in the southwestern United States, p. 60-76. In Proc. of Symp. on Stream Channel Modification. USDI Fish and Wildl. Serv., Off. Biol. Serv., Wash., D.C.

Clary, W. P., M. B. Baker, Jr., P. F. O'Connell, T. N. Johnsen, Jr. and R. E. Campbell. 1974. Effects of pinyon-juniper removal on natural resource products and uses in Arizona. USDA For. Serv. Res. Pap. RM-128, Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo., 28 p.

Cooke, R. U. and R. W. Reeves. 1976. Arroyos and environmental change in the American Southwest. Oxford Res. Stud. in Geog., Clarendon Press, Oxford, England, xii + 213 p.

Dickson, J. G. 1978. Forest bird communities of the bottomland hardwoods p. 66-73. In R. M. De Graaf (Tech. Coord.), Proc. of the Workshop: Manag. of southern forests for non-game birds. USDA For. Serv. Gen. Tech. Rpt. SE-14, SE For. Exp. Stn., Asheville, N. Carol.

Dobyns, H. F. 1978. Who killed the Gila? Jour. of Ariz. Hist., 19:17-30.

Dolan, R., A. Howard, & A. Gallenson. 1974. Man's impact on the Colorado River in the Grand Canyon. Amer. Sci. 62:392-401.

Dolan, R., B. Hayden, A. Howard, & R. Johnson. 1977. Environmental management of the Colorado River within the Grand Canyon. Envir. Mgmt., 1(5):391-400.

Douglas, C. L. and R. R. Johnson. 1972. Highways and their impact on the wildlife of the pinyon-juniper-oak woodland and grassland in north-central Arizona. Ariz. Highway Dept., iv + 111 p. & 31 p. append.

Dracup, J. A. 1977. Impact on the Colo. R. Basin & southwest water supply. p. 121-132. In Wallis, J. (Ed.); Climate, climatic change and water supply. Nat'l Acad. Sci., Wash., D.C.

Emlen, J. T. 1974. An urban community in Tucson, Arizona: deviation, structure, regulation. Condor 76:184-197.

Emory, W. T. 1858. Notes of a military reconnaissance from Fort Leavenworth in Missouri to San Diego in California. Wendell and Van Benthvysen, Wash., D. C. 614 p.

Ffolliott, P. F. and D. B. Thorud. 1974. Vegetation management for increased water yield in Arizona. Agr. Exp. Stn., Univ. of Ariz., Tucson. iii + 38 p.

Finzel, J. E. 1964. Avian populations of four herbaceous communities in southeastern Wyoming. Condor 66:496-510.

Gavin, T. A. and L. K. Sowls. 1975. Avian fauna of a San Pedro Valley mesquite forest. Jour. Ariz. Acad. of Sci. 10:33-41.

Haldeman, J. R., R. P. Balda & S. W. Carothers. 1973. Breeding birds of a ponderosa pine forest and a fir, pine, aspen forest in the San Francisco Mountain area, Arizona. Mus. of N. Ariz., Tech. Bull No. 12:1-21.

Hartranft, C. W. 1908. An Arizona hunt. The Oologist, 25:85-87.

Haury, E. W. 1967. First masters of the American desert, the Hohakam. Natl. Geogr. 670-695.

Hering, L. 1957. Breeding bird census: Pinyon-juniper forest. Audubon Field Notes 11:448-449.

Hoffmeister, D. F. 1971. Mammals of Grand Canyon. University of Illinois Press. 183 p.

Horton, J. S. 1973. Evapotranspiration and water research as related to riparian and phreatophyte management. USDA For. Serv. Misc. Publ. No. 1234, U.S. Govt. Print. Off., Wash., D. C. 192 p.

Horton, J. S. and C. J. Campbell. 1974. Management of phreatophyte and riparian vegetation for maximum multiple use values. USDA For. Serv. Res. Paper RM-117. Rocky Mtn. For. and Range Exp. Stn., Ft. Collins, Colo. 23 p.

Hubbard, J. P. 1977. A biological inventory of the lower Gila River Valley, New Mexico. N. Mex. Dept. Game & Fish, 56 p.

Hunt, C. B. 1967. Physiography of the United States. W. H. Freeman and Co., San Francisco, 480 p.

Johnson, R. R. 1970. Tree removal along southwestern rivers and effects on associated organisms. Amer. Phil. Soc., Yearb. 1970. p. 321-322.

Johnson, R. R. 1972. The effects of "civilization" on the avifauna of the Salt River Valley (abstract). Jour. Ariz. Acad. Sci. Proc. Suppl. 19.

Johnson, R. R., L. T. Haight & J. M. Simpson. 1977. Endangered species vs. endangered habitats: a concept, p. 68-79. In Johnson, R. R. & D. A. Jones (Tech. Coord.) Importance, preservation and management of riparian habitat: a symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mt. For. & Range Exper. Stn., Ft. Collins, Colo.

Johnson, R. R., and Dale A. Jones, Tech. Coord. 1977. Importance, preservation and management of riparian habitat: A symposium. [Tucson, Ariz., July 9, 1977.] USDA For. Serv. Gen. Tech. Rpt. RM-43, 217 p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

Korte, P. A., and L. H. Fredrickson. 1977. Loss of Missouri's lowland hardwood ecosystem, p. 31-41. In Trans. of the 42nd North Amer. Wildl. and Nat. Resources Conf., Wildl. Mgmt. Inst., Wash., D.C.

Kusler, J. 1976. A perspective on floodplain regulations for floodplain management. Dept. of the Army, Off. of the Chief of Engineers, Wash., D. C.

Lee, R. F. 1970. The antiquities Act of 1906. USDI Natl. Park Serv., Off. of Hist. and Historic Architecture, Eastern Serv. Center, Wash., D. C. iv + 120 p.

Leopold, A. 1949. A Sand County almanac. Oxford Univ. Press, New York. xiii + 226.

Leopold, A. 1933. Game Management. C. Scribner's Sons, N.Y. 481 p.

Merriam, C. H. 1890. Results of a biological survey of the San Francisco Mountain region and desert of the Little Colorado, Arizona. North Am. Fauna No. 3, U.S. Govt. Print. Off., Washington, D. C. 136 p., 13 plates + 5 maps.

Miller, A. H. 1951. An analysis of the distribution of the birds of California. Univ. of Cal. Publ. Zool. 50:531-643.

Miller, R. R. 1946. Gila cypha, a remarkable new species of cyprinid fish from the Colorado River in Grand Canyon, Arizona. Jour. Washington Acad. Sci. 36:409-415.

Minckley, C. O. and D. W. Blinn. 1976. Summer distribution and reproductive status of fish of the Colorado River and its tributaries in Grand Canyon National Park and vicinity during 1975. Colorado River Technical Report No. 14, Grand Canyon National Park. 17 p.

Odum, E. 1959. Fundamentals of ecology. W. B. Saunders Co., Philadelphia. xvii + 546 p.

Ohmart, R. D., W. O. Deason & C. Burke. 1977. A riparian case history: the Colorado River. p. 35-47. In Johnson, R. R. & D. E. Jones (Tech. Coord.); Importance, Preservation and Management of Riparian Habitat: A symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Stn., Ft. Collins, Colo.

Ohmart, R. D., and R. W. Smith. 1973. North American Clapper Rail (Rallus longirostris) literature survey with special consideration being given to the past and current status of yumanensis. Bur. of Reclamation, Boulder City, Nev., 45 p.

Pacific Southwest Interagency Committee. 1966. Phreatophyte symposium 66-3 meeting. Pacific Southwest Interagency Comm., Albuquerque. 57 p.

Phillips, A., J. Marshall & G. Monson. 1964. The birds of Arizona. Univ. of Arizona. Press, Tucson. xviii + 212 p.

Powell, J. W. 1875. Exploration of the Colo. River of the west and its tributaries. U.S. Govt. Print. Off., Wash., D.C. 291 p.

Raitt, R. J. and R. L. Maze. 1968. Densities and species composition of breeding birds of a creosotebush community in southern New Mexico. Condor 70:193-205.

Rappole, J. H. and D. W. Warner. 1976. Relationships between behavior, physiology and weather in avian transients at a migration stopover site. Oecologia, 26:193-212.

Reynolds, H. G., and Johnson, R. R. 1964. Habitat relations of vertebrates of the Sierra Ancha Experimental Forest. U.S. Forest Serv. Res. Paper RM-4, illus. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo. 16 p.

Ruffner, G. A., N. G. Czaplewski & S. W. Carothers. 1978. Distribution and natural history of some mammals from the Inner Gorge of the Grand Canyon, Arizona. Jour. Ariz. Nev. Acad. of Sci. 13:85-91.

Salt River Project. 1970. The taming of the salt. Community Rel. Dept., Salt River Proj., Phoenix, Ariz. 143 p.

Salt River Project. No date a. Major facts about the Salt River Project. Salt River Project, Phoenix, Ariz. 40 p.

Salt River Project. No date b. A valley reborn: the story of the Salt River Project. Salt River Proj., Phoenix, Ariz. 25 p.

Sands, A. (Ed.) 1977. Proceedings of the symposium on riparian forests in California: their ecology and conservation. Inst. of Ecol. Publ. No. 15, Univ. of Cal., Davis. vi + 122 p.

Smith, G. E. P. 1936. Water supplies, p. 37-46. In Shantz, H. L., Arizona and its heritage. Univ. of Ariz. Gen. Bull. #3, Univ. of Ariz. Press, Tucson.

Stevens, L. E., B. T. Brown, J. M. Simpson & R. R. Johnson. 1977. The importance of riparian habitat to migrating birds, p. 156-164. In Johnson, R. R. & D. A. Jones (Tech. Coord.); Importance, preservation and management of riparian habitat: a symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mt. For. & Range Exper. Stn., Ft. Collins, Colo.

Suttkus, R. D., and G. H. Clemmer. 1977. The Humpback chub, _Gila cypha_, in the Grand Canyon area of the Colorado River. Occas. Pap. Tulane U. Mus. Nat. Hist., Tulane U., New Orleans, La. No. 1, 30 p.

Suttkus, R. D., G. H. Clemmer & C. Jones. 1978. Mammals of the riparian region of the Colorado River in the Grand Canyon area of Arizona. Occ. Pap. Tulane U. Mus. of Nat. Hist. No. 2, 23 p.

Suttkus, R. D., G. H. Clemmer, C. Jones & C. R. Shoop. 1976. Survey of fishes, mammals and herpetofauna of the Colorado River in Grand Canyon. Colo. R. Res. Tech. Rpt. No. 5. USDI Natl. Park Serv., Grand Canyon Natl. Park. 48 p.

Thomas, J. W., C. Maser & J. E. Rodiek. 1978. Edges - their interspersion, resulting diversity and its measurement. p. 91-100. In DeGraaf, R. M. (Tech. Coord.); Proc. of workshop on nongame bird habitat management in the coniferous forests of the western United States. USDA For. Serv. Gen. Tech. Rpt. PNW-64, Pacific Northwest For. and Range Exp. Stn., Portland, Ore.

Tomko, D. S. 1975. The reptiles and amphibians of the Grand Canyon. Plateau 47:161-166.

Tomoff, C. S. 1974. Avian species diversity in desertscrub. Ecol. 55:396-403.

Turner, R. M. 1974. Quantitative and historical evidence of vegetation changes along the Upper Gila River, Arizona. U.S. Geo. Surv. Prof. Paper 655-H, U.S. Govt. Print. Off., Wash., D.C. vi + 20 p.

U.S. Dept. of Interior, Bureau of Reclamation. 1977. Colorado River Basin Salinity control project: Title 1 Division, desalting complex unit, Arizona: Status Report. Boulder City, Nevada 215 p. + maps.

U.S. Fish and Wildlife Service. 1973. Threatened wildlife of the United States. USDI Fish and Wildlife. Serv., Bur. of Sport Fisheries and Wildl., Office of End. Species and Int. Activities, Wash., D.C. xiii + 289 p.

Welty, G. C. 1975. The life of birds. W. B. Saunders, Philadelphia, xv + 623 p.

Wigal, D. D. 1973. A survey of the nesting habitats of the white-winged dove in Arizona. Ariz. Game and Fish Dept. Spec. Rpt. No. 2, vi + 37 p.