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RIPARIAN HABITATS AND RECREATION: INTERRELATIONSHIPS AND IMPACTS IN THE SOUTHWEST AND ROCKY MOUNTAIN REGION

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ABSTRACT

Riparian habitats are characterized by outstanding species richness and population densities of both plants and animals. Increasing recreational pressures on these ecotones between water and surrounding uplands are forcing management agencies to re-analyze consumptive versus non-consumptive resource allocations.

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INTRODUCTION AND STATEMENT OF THE PROBLEM

Great civilizations of the world have developed along river systems almost without exception. In arid and semi-arid lands human settlement patterns follow flowing water systems, for it is along the river and stream corridor that water is most easily obtained for drinking and household use, for domestic livestock and irrigation of crops. Besides an abundance of water, the riparian areas are also characterized by other abundant resources, including game and fish, livestock forage and shade, fuelwood, timber, and lastly and importantly, a verdant, idyllic setting for recreational and aesthetic purposes.

In the arid southwest, before the invasion of Spanish explorers in the 1500's, Indians built cliff dwellings, pueblos and jacals along western rivers. Although they left no written records, their prehistoric ruins, ranging from single rooms to vast major living centers and agricultural complexes, remain as evidence of the importance of water to their way of life.

Water is just as important today. Our quality of life is related to the quality of our water. The quality of recreation is also related to the availability of water and its quality. As water quality diminishes so does our "standard of living", including recreational opportunities.

Riparian resources, so dependent on flowing water, are in limited supply. As with gold, diamonds, outstanding management expertise, exceptional research ability, or water in Death Valley, their scarcity makes them valuable. Add to their limited quantity the fact that these riparian resources have been sought after by a vast array of Indians, military expeditions, settlers, farmers, wildlife, recreationists and city dwellers and their value increases. Yet, improper management of western water courses and their attendant riparian ecosystems has decimated this once rich heritage. Proper multiple use management is as important for these valuable riparian areas as for any other known, for few other natural resources are sought by such a diversity of interests for so many purposes.

Our purpose here is to document the precarious status of our dwindling riparian resources. This paper presents the state of the art, discussing the recreational importance of streams and rivers and their associated riparian ecosystems in the Rocky Mountain Region. We address the importance of the proper protection and management of watersheds and their riparian ecosystems. This protection and management is critical to both environmental and cultural values, including water quality, recreational and wildlife values, and consequently, the interrelationship of these factors with "civilization" itself.

CHARACTERISTICS OF RIPARIAN HABITATS

Ecologists in the eastern United States tend to be more restrictive than those in the more arid west in the use of the term "riparian". Many eastern biologists would restrict the definition of riparian areas to the habitats closely paralleling bottomlands, floodplains, or first terraces along flowing streams. Authorities in the more arid sections of the West commonly extend the use of the term to include banks of arroyos which may flow only a few days each year at best, and even to desert oases. Most water sources, whether surface or ground water near the surface, in desert areas will have associated riparian vegetative assemblages.

Investigators generally agree that riparian habitats and their associated ecosystems along the banks of a stream are similar to those occurring along the banks of lakes, swamps, marshes, and sometimes seas and coastlines. Thus, the term can be applied to the banks of permanently flowing streams, to playas (dry lake beds), desert arroyos or to systems somewhere in between (Austin 1970).

For the purposes of this paper, we are using a biotic definition of riparian ecosystems without either ignoring or giving undue emphasis to the physical attributes of riparian areas. We use the term "riparian" to refer to areas where soil moisture is sufficiently high to support plant and animal communities differing from the surrounding, drier uplands. Lowe (1964) defines a riparian association as "one which occurs in or adjacent to drainageways and/or their floodplains and which is further characterized by species and/or life-forms different from that of the immediately surrounding non-riparian climax".

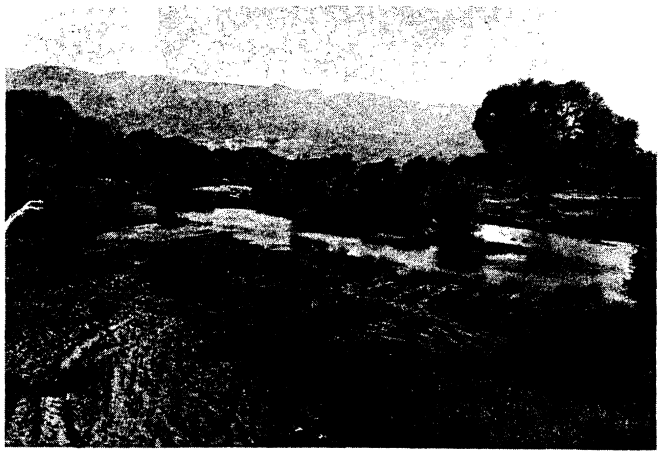

Figure 1.--Perennial riparian habitat dominated by Fremont cottonwood-Goodding willow Association (Brown et al. 1979) along the Verde River in Yavapai County, Arizona, elevation 3150 feet. Photograph looking south from the U.S. Geological Survey gauging station at White Bridge, Camp Verde, June 1981. Disturbance as evidenced by vehicle tracks is present in the foreground. (Photo by Johnson).

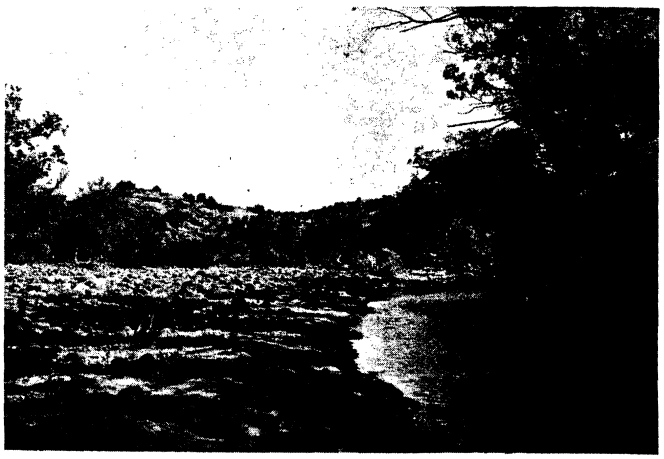

Figure 2.--Dry Beaver Creek, an intermittent stream in its upper reaches and an interrupted perennial stream here. Perennial riparian habitat of Goodding willow and intermittent riparian habitat of Platanus wrightii-Fraxinus velutina-Populus fremontii Association (Brown et al. 1979). Photograph taken south of the Arizona Highway 179 bridge, June 1981, Yavapai County, Arizona, elevation 3700 feet. (Johnson).

Western riparian habitats can be divided into three basic types (Johnson et al. In press): (a) perennial - associated with permanent water (Figure 1), (b) intermittent - areas where water is available for only a few months of the year, often during one or two seasons (Figure 2) and (c) ephemeral - found along watercourses which flow irregularly for short periods (less than one month) after local precipitation (Figure 3). The type of habitat and its associated ecosystem varies with elevation, latitude, edaphic and other factors. For example, the Colorado River forms the major natural recreational resource in the Rocky Mountains and Southwest. Perennial riparian habitat along the Colorado and its tributaries varies from Cottonwood-Willow forest at lower elevations through Mixed Broadleaf Series (Brown et al. 1979), such as Sycamore-Ash-Cottonwood at intermediate elevations, to scrubby willows along alpine tributaries to the Colorado. Western riparian ecosystems are generally characterized by the following:

1) They are biogeographical "islands" that support faunas and floras usually composed of a larger number of species and individuals than inhabit the surrounding environs (Brown and Minckley. In press). Riparian areas are some of the world's most productive ecosystems. This is the case not only for natural ecosystems, but for agricultural systems as well. Consequently, "bottomlands" are heavily utilized for growing crops, grazing, and urbanization. When major species of plants in the riparian areas are the same or similar to those in the surrounding uplands, the productivity is almost always greater along the water's edge. This high productivity is commonly carried up through the various trophic levels of a food pyramid, being expressed in natural ecosystems by biomass of insects, birds, or other animals, and in agricultural systems by pounds of crops or livestock produced per unit area.

2) Riparian ecosystems often occur in linear habitat, such as along the banks of a stream or lake, and have a very noticeable edge effect. Odum (1959) defined the edge effect as "the tendency for increased variety and density at community junctions."

Figure 3.--Ephemeral riparian habitat dominated by ironwood (Olneya tesota) and mesquite at Saguaro National Monument (West), Tucson, Pima County, Arizona, elevation 2600 feet. Water flows irregularly immediately following heavy local precipitation. (Photo by Kingsley, 1981).

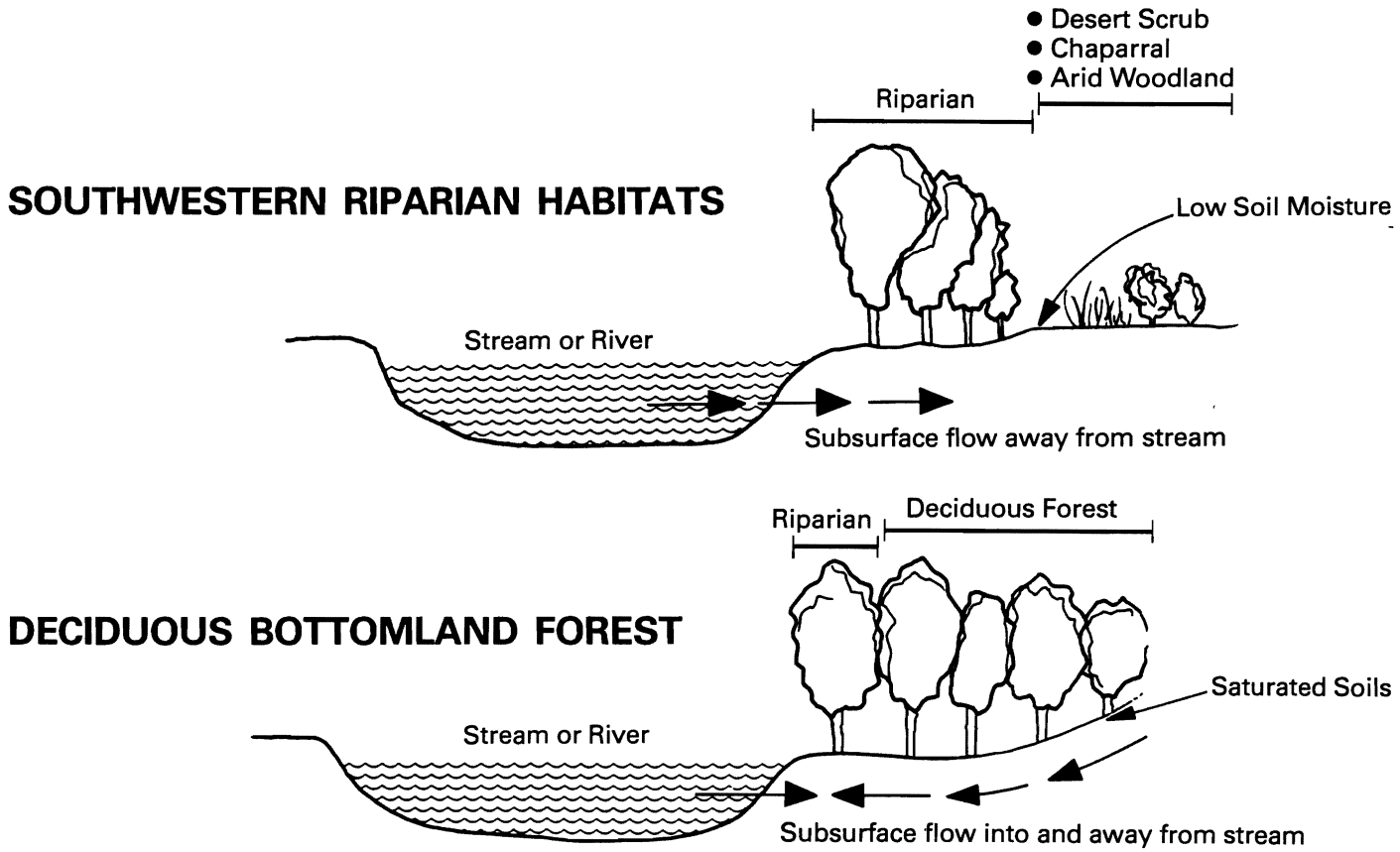

Figure 4.--Generalized comparison of southwestern riparian habitats and eastern deciduous bottomland forests.

3) These ecosystems are ecotonal in nature, supporting species of plants and animals not occurring commonly in either the upland habitat on one side or aquatic habitat on the other. Thus, these areas frequently have vegetation types different from their surroundings (e.g., cottonwood-willow in a grassland or desert scrub region, or deciduous forest in a mixed conifer region (Odum 1978, Johnson 1978).

There tend to be certain characteristic differences between riparian areas in the Southwest/Rocky Mountain Region and the Eastern United States (Figure 4). Some of these features are listed in Table 1.

Although we lack quantitative data, we have hypothesized a generalized differentiation between the riparian areas of the more mesic eastern streambottom forests and those restricted riparian areas of the more arid Southwest (Figure 4). Our proposed model is based primarily on the hypothesis that in arid land habitats the distance a riparian habitat extends away from the streambank is a function of a soil moisture gradient contributed by percolation of groundwater laterally from the stream. In more mesic areas, we see the soils adjacent to the stream as being saturated, or nearly, so, from subsurface water originating throughout the watershed moving downslope in response to gravity. By definition then, we characterize eastern streams as nutrient lmited, gaining systems (effluent) contrasted to Southwestern and other arid systems as water limited, losing systems (influent; Meinzer 1923).

In the same sense that these riparian areas concentrate natural resources, (energy, nutrients, plants, and animals), they also serve to concentrate human resources. This is true for agricultural, urban, or recreational purposes. Unfortunately, in many cases the characteristics which originally attracted humans are in turn destroyed by improper management and usage. Swift and Barclay (1980) estimate that "at least 70% of the original area of riparian ecosystems has been cleared" in the United States. In the absence of comprehensive studies for our region we present figures for the large, agricultural Sacramento River Basin of California where it has been estimated that approximately 775,000 acres of riparian woodland occurred in 1848-1850. By 1952, approximately 100 years later, about 20,000 acres remained and "today's estimate of 12,000 acres is probably generous" (Smith 1977). Thus, less than 2% of the original riparian habitat is left (Figure 5). Although we find no similar estimates of the percentage of riparian forest remaining in the Rocky Mountain Region, a great

Table 1.--Characteristics of Western and Eastern riparian zones.

SOUTHWEST/ROCKY MOUNTAIN REGION	EASTERN UNITED STATES
1. Highly visible, more abrupt change from surroundings.	1. Commonly grades gradually from drier uplands to wettest bottomlands.
2. Riparian vegetation is supplied with water from the stream (losing or influent system). Large springs are main source of flowing water.	2. Water drains into bottomlands from throughout the surrounding uplands, providing water for the riparian vegetation Water flows into and joins the stream (gaining or effluent system).
3. Less stable channels, open to more frequent shifts in stream channel, relatively barren banks, more easily eroded.	3. More stable, vegetated banks. During floods, water slowed down by vegetation along banks, reducing erosion.
4. Quick runoff from relatively barren hills.	4. Vegetation on surrounding terrain holds back water allowing slower drainage.

similarity exists between the agricultural and urban development in our Region with that of California's Central Valley. Probably less than 10% of the native cottonwood-willow type remains in the lowland, perhaps less than 5%. Babcock (1968) estimated 279,000 acres of phreatophyte (riparian vegetation) in Arizona, while Ffolliott and Thorud (1974) estimated approximately 300,000 acres (280,000-320,000). This is less than 0.4% of the total land area in Arizona.

RIPARIAN AND RECREATIONAL HISTORY

In order to address the subject of recreational values of Rocky Mountain and Southwestern streams and their attendant riparian ecosystems we must first examine settlement patterns and the history of riparian use in the region. Although much of the information discussed here may at first glance seem ancillary to our subject it will soon become evident that the degradation of riparian habitats is inextricably linked to a deterioration in recreational values for the region.

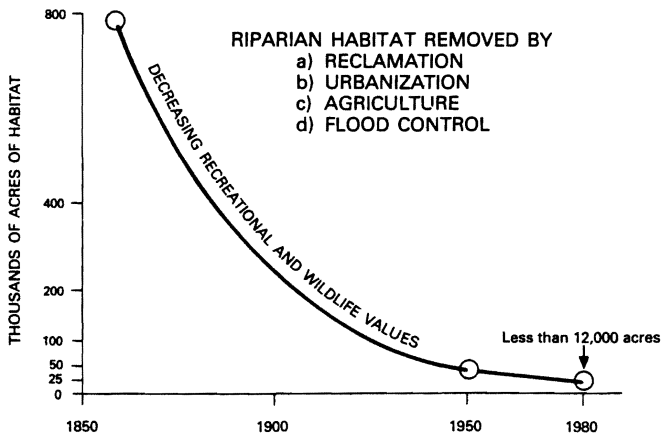

Figure 5.-- Change in extent of original riparian habitat along the Sacramento River, California, from 1850 to 1980 (after Smith 1977). Decrease in riparian habitat corresponds to decrease in recreational and wildlife values.

Our literature survey included an extensive computerized search for information regarding riparian recreation throughout our area of concern. We have presented the best known examples to emphasize the declining condition of our western riparian habitats. This includes examples of "consumptive" uses such as hunting and fishing as well as the "nonconsumptive" uses: birdwatching, camping, hiking, and backpacking, etc. Most of our references, both to recreational studies and studies regarding man's impacts on these recreational resources, refer to the arid and semi-arid areas of the region. For example, the more arid, unforested sections of the Colorado River system are lined by four National Parks, three National Recreation Areas, and a plethora of National Monuments, National Historic Sites, and National Forests. It is here, where water is scarce, that recreational demands are greatest.

Early explorers in the western United States and the settlers who followed them exploited natural resources in immediate and practical terms. Recreation in the form we know it was an impractical and nonexistant luxury. Trappers, prospectors, soldiers, ranchers, farmers, and merchants concentrated on the crucial tasks of securing food and shelter and the rudiments of social organization. Many had little schooling; some were illiterate. These early explorers and settlers left

sparse information about the riparian ecosystems they encountered as they spread westward. The few available records include narratives containing little quantifiable information, except occasionally the practical assessment of timber for the building of an army post or a trapper's count of the pelts obtained in a season. These settlers, still few in numbers, shared the view that riparian resources existed solely for human usage, and that the resource was infinite in supply.

Explorers and settlers were not the only ones who left us incomplete biological information. Even members of official scientific and/or exploratory parties were usually not ecologists; their extensive writings often treated vegetation and wildlife in general terms. This is true for Lt. Emory's (1848) explorations on the Gila River in the 1840's and even to Major Powell's (1961) famous explorations on the Colorado River in the 1860's. We do not have, nor will we ever have, an accurate pre-dam species list for those extensively dammed and heavily modified river systems. We can reconstruct relatively accurate lists by extrapolation. However, information regarding relative densities, population densities, or more sophisticated data is completely lacking. In a rugged, sparsely settled land, hunting and fishing were a necessity. Other recreational potentials, water quality, and similar factors were not to be envisioned for almost a century.

By the mid-1900's it would seem that we would have learned the importance of inventorying riparian ecosystems before their demise. Such was not the case in the construction of Glen Canyon Dam on the Colorado River, in the early 1960's and the resulting inundation of Glen Canyon and the formation of Lake Powell. Before the dam's completion, responsible government agencies funded the gathering of biological information (Woodbury et al. 1959) about the area to be inundated when the lake filled. However, no information was gathered for the stretch of the Colorado River which would be greatly impacted downstream from Glen Canyon Dam for 255 miles to Lake Mead. This included 240 miles of a unique riverine ecosystem, comprising the river corridor of Grand Canyon National Park specifically set aside for its natural and recreational value. In addition to Grand Canyon's geologic grandeur and other natural attributes, its segment of the Colorado river support's North America's finest whitewater recreation. Ironically, both Glen Canyon National Recreation Area and Grand Canyon National Park (as well as Lake Mead National Recreation Area) are administered by the National Park Service. Effects of Glen Canyon Dam on water quality and other recreational interactions will be addressed later in this paper through a case history study of the Colorado River in Grand Canyon.

Nineteenth century explorers and settlers arrived in the West from the eastern United States only to encounter ecosystems already modified by humans. The Salt River Valley in south-central Arizona, for example, had been settled at least two millennia earlier (Johnson 1978). This valley has supported continuous 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. 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).

After the collapse of Hohokam culture, a collapse thought to be related to climatic and/or agricultural practices, and 300 years before the arrival of Anglo immigrants, Spanish explorers traveled many of the southwestern river valleys. They were often in search of gold or other adventures; thus, their biological notes were commonly less complete even than those of the later Anglo explorers. The few records the Spanish left mention such rarities as Thick-billed Parrots (Rhynchopsitta pachyrhyncha) near Camp Verde, Arizona in 1583 (fide Phillips et al. 1964). We shall never know what other species unknown for this area today were seen but not mentioned.

IMPACTS TO RIPARIAN ECOSYSTEMS

As the disproportionately high natural values of riparian habitats have become known, the consumptive practices influencing habitat quality have recently fallen under intense scrutinity. Previously unquestioned practices such as livestock grazing, floodplain farming, groundwater pumping, and water control projects have been studied and found to have profound effects on the probability of long-term survival of portions of the riparian habitat under extensive development. Some of these practices, their damaging effects and the possibilities for a balanced use through mitigation are discussed below.

Grazing

The origin of livestock grazing in the western United States may be traced directly to the impetus of Spanish exploration of the early 1500's. Spanish missions were invariably established along permanent water courses, and domestic livestock were an integral component of the mission's food supply. Then, as now, the livestock congregated in riparian areas where forage, water and shade were easily available. The burning of large expanses of the riparian forest to drive cattle into the open for roundup was an early practice (Wagoner 1949). Thus, early Anglo explorers arrived to find riverbottoms already heavily impacted. Coues (1874) wrote of the Lower Colorado near Fort Yuma:

> But in Arizona, "no bush without a thorn"; even the oaks have prickly leaves. Wide spreading mimosas stretch their skinny arms and clutch us, and the claws of straggling acacias and mezquites (sic) take hold. Lesser shrubs rattle prickly seeds around us; we are confronted with great piles of driftwood, and hedged about with compact heaps of twigs and rushes, stranded by the last overflow. But fortunately the place is intersected with cattle paths, along which we can thread a devious way;...

The complex impacts of grazing on riverine ecosystems are still not entirely understood, more than four centuries after the introduction of domestic livestock to the new world. Several recent papers and even symposia have addressed this issue (Boldt et al. 1978, Cope 1979, Gregg 1979, Menke in press (fide Behnke 1979)). One of the more noticeable effects of grazing is the lack of reproduction of cottonwoods (Populus spp.) and some other riparian species whose seedlings are eaten by livestock (Glinski 1977). Without at least periodic reproduction, many riparian areas are becoming characterized by even-age stands composed of aging trees. As these stands become senescent, there is a definite lack of recruitment that would guarantee an indefinite survival of the riparian forest. Seedlings of the especially palatable cottonwood tree require two to five years growth in lowland habitats (personal observations) before their leaves are out of reach from grazing livestock. Few, if any, riparian areas in the arid Southwest are on a rest-rotation grazing system keyed to the protection and ultimate survival of riparian tree species. Other impacts resulting from excessive grazing in riparian habitats include increased erosion and degradation of streams resulting in damage to local and regional fisheries (Benke and Raleigh 1978) and lowering of water quality and recreational values (Cope 1979). The scope of grazing impacts on riparian areas is summarized by Benke (1979):

> A BLM report on salinity problems in the upper Colorado River basin by Bentley et al. (1978) identified livestock grazing as the greatest cause of accelerated erosion and associated salt loading of the Colorado River. The costs to downstream water users in the basin are estimated to be more than $330,000 for each additional mg/l of salt concentration. On the basis of this study, Eggleston and Bentley (1977) calculated that the elimination of livestock grazing from highly erodible public lands would have a benefit-cost ratio of 5.9:1 considering only the costs of increased salt concentration to downstream water users. If fisheries, wildlife and recreation losses were to be estimated from watersheds subjected to accelerated erosion, and the loss of downstream reservoir storage to sediment filling were added the total costs to society caused by past and present grazing systems on highly erodible lands would be enormous in comparison to the benefits of meat production...The riparian ecosystem is a zone of highly concentrated values associated with fish, wildlife, recreation, and water quality. Multiple use management on federal lands has often severely degraded riparian zones and associated values. This abuse must be corrected.

Irrigation

The more arid the region the more critical become the scarce water supplies. A recent paper by Schrupp (1978) compared wildlife values in lowland riverine habitats to other habitats in Colorado. He found that "all habitat evaluations displayed a common factor in that lowland river and stream habitat rated as one of, if not the most important habitat types for wildlife. Unfortunately, this is also true for grazing, farming, and urbanization. Thus, competition for the water, aquatic, and riparian resources of these lowland rivers is probably as great as, or greater than, any other habitat type in North America."

In order to maximize water availability for agriculture, a vast number of "water salvage" projects have been undertaken. These include water storage projects and watershed management, including phreatophyte control. Phreatophyte, coined by Meinzer (1923), from Greek meaning "well plant", refers to those species of plants growing directly adjacent to the watercourse. These plants receive their water directly from the stream or underground water table and at one time were targeted for removal by water salvage concerns - and other types of "vegetation management". The former is designed to store existing flowing water, the latter to increase water yields from watersheds. Although volumes have been written on each of these subjects, we can only discuss them briefly in this limited space.

The Bureau of Reclamation was established in 1902-03. The first major dam, Theodore Roosevelt Dam, was completed in 1911 and provided power and irrigation water for the Salt River Valley Water Users of Arizona (now Salt River Project). Roosevelt Lake provided recreational opportunities for the few who took advantage of them at that early date. This dam, constructed just below the confluence of Tonto Creek with the Salt River (central Arizona) also caused the inundation of a vast prehistoric settlement (Solado valley ruins) and an extensive cottonwood forest. The role of this and similar dams in the loss of most of Arizona's native lowland habitat has been discussed by Johnson et al. (1977) and Johnson (1978). Dams are generally a double menace to river ecosystems, inundating wildlife habitat and recreation areas above the dam while dessicating those downstream.

A large percentage of the species compris-

ing today's depauperate remnants of Southwest riparian habitats is salt cedar (Tamarix chinensis). This species, introduced as an ornamental into the United States more than 100 years ago, spread rapidly. It occurred in 15 of 17 western states by 1961 and increased from an area estimated at approximately 10,000 acres in 1920 to more than 900,000 acres in 1961 (Figure 6, Robinson 1965). The taxonomy and biology of Tamarix has been studied extensively by Horton (1977). Wildlife and recreational values are generally very low for salt cedar (Anderson et al. 1977) except for White-winged (Zenaida asiatica) and Mourning Doves (Z. macroura). The highest nesting concentrations presently recorded for these important game species occurs in Tamarix thickets (Wigal 1973).

Tamarix commonly invades riparian areas disturbed by reclamation projects such as irrigation reservoirs (Potter 1979). This is true for most of the lowland segments of the Colorado River and its tributaries, and has led to the creation of the term "reclamation disclimax" for this disturbed vegetation type (Johnson 1978). It is the major woody riparian exotic species in the Rocky Mountain Region except for the introduced Russian olive (Elaeagnus angustifolia) which is prevalent in rivers at high elevations on the Colorado Plateau and along colder, northern rivers. Tamarix can eliminate native riparian species such as cottonwood and seepwillow (Turner 1974). The high water consumption of Tamarix (van Hylckama 1974, 1980) led to extensive phreatophyte control programs to control or eradicate the species, especially on the Gila River (Culler et al. 1970) during the 1960's. Unfortunately, many native species were also directly removed during those programs. Although Tamarix usually provides poor conditions for outdoor recreation, including camping, hiking and fishing, many of these native species, such as cottonwoods, willows and sycamores, provide outstanding recreational sites.

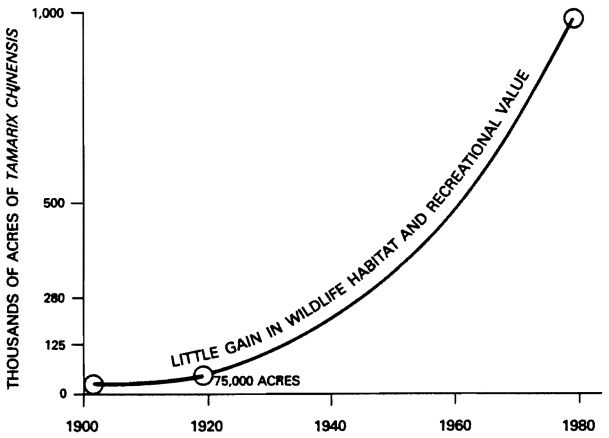

Figure 6.--Change in extent of riparian acreage of Tamarix chinensis in western states from 1900 to 1980 (after Robinson 1965). There is little gain in wildlife habitat and recreational value associated with the increase in Tamarix.

Watershed and Vegetation Management

Watershed management can be divided into (a) erosion control and (b) vegetation manipulation. Most of these activities have been directed toward improving forage, timber, and water yields. Erosion control has been largely conducted in relation to disturbances caused by lumbering, grazing, and wildfires. Commonly used practices include rest-rotation grazing, reseeding, and construction of water control structures. Gully control is commonly by check dams (Heede 1976) which often lead to a reestablishment of grasslands or forests. In desert situations, water impoundment and diversion structures often create riparian, lake, or marsh habitats (Conn et al. 1975).

Vegetation removal (usually called vegetation management or manipulation) is conducted both on upland and riparian sites. Juniper-pinyon (Juniperus-Pinus) woodland, chaparral, and mesquite (Prosopis spp.) are often controlled by mechanical means. Bulldozed or chained junipers and mesquite trees are often used for firewood. Chaparral and mesquite are also controlled by herbicides. Although treatment of an area may be primarily concerned with converting brushland to grassland, increased water yields commonly accompany the conversion. A good example of this is Brushy Basin, an 8,000 acre watershed in central Arizona where range conditions were greatly improved after conversion by controlled burning (Moore and Warskow 1973). In addition, ephemeral or intermittent streams often flow longer throughout the year after treatment; some of them even convert to permanent streams (Hibbert et al. 1974). Unfortunately, riparian vegetation has usually been removed in such programs without proper regard for wildlife and recreational activities.

Although there is little doubt that watershed manipulation can increase water yields, the economic feasibility of these past practices is questionable, especially when values for other, often competing, uses are considered. One of the most noted plans for water harvest at the expense of other values was the "Barr Report" (1956). More recently Ffolliott and Thorud (1974) presented a plan to increase water yield by 600,000 to 1,200,000 acre feet/year in the mixed conifers, ponderosa pine, and chaparral vegetation types of Arizona. Brown et al. (1974) found chaparral conversion under ideal conditions feasible in some areas but not in others.

Phreatophyte control is apparently the most damaging type of vegetation management. Removing vegetation from floodplains is usually done by chain saws or bulldozers, often in conjunction with stream channelization projects. Our own research findings indicate that removal of woody vegetation reduced wildlife usage of streams to almost nothing. It has been suggested by proponents of these programs that phreatophyte removal may increase diversity, and thereby even improve wildlife values

(Arnold 1972). On the contrary, our studies in the Verde Valley (Carothers and Johnson 1971, Johnson 1971) showed a straight-line relationship between the number of mature cottonwood trees/acre and the number of nesting birds; thus, the fewer the trees, the fewer the birds (Figure 7).

Historically, the Pacific Southwest Interagency Committee (Federal and State agencies) established a Phreatophyte Subcommittee in 1951. This subcommittee was especially concerned with the spread of salt cedar and associated problems; e.g., water usage through evapotranspiration (van Hylckama 1980), and clogging of river channels. Its philosophy can be better understood by examining the proceedings of its third symposium, held in 1966, where only one of the eight papers presented addressed multiple use values (Woods 1966), rather than just water yield. Although earlier eradication programs were aimed largely at salt cedar, as time progressed, more and more native riparian forests were also destroyed. In addition to loss of shade and reduction in catchable fish (Stone 1970), high value recreational sites apparently eroded more rapidly after the removal of trees (personal observations).

Scientific symposia commonly had at least one paper on phreatophytes; e.g., a special symposium on "Problems of the Upper Rio Grande" (Duisberg 1957). One entire symposium was held on "Water Yield in Relation to Environment in the Southwestern United States" by the prestigious American Association for the Advancement of Science (Warnock and Gardner 1960). Actual eradication programs were generally conducted by agencies such as the Bureau of Reclamation, U.S. Army Corps of Engineers, and local water

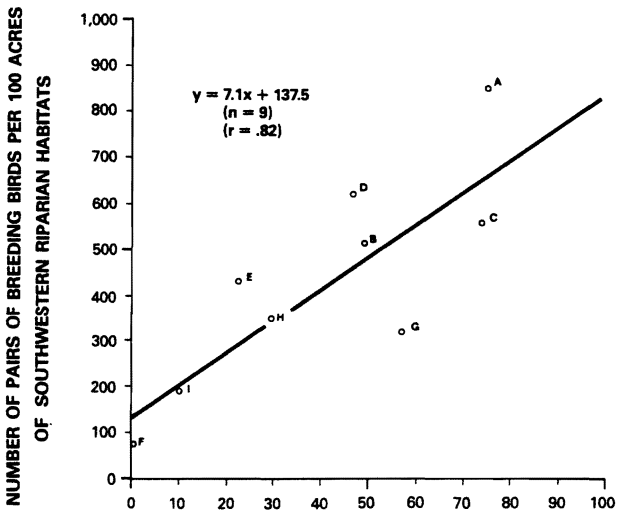

Figure 7. Relationship of breeding bird density to density of native riparian tree species (specifically cottonwood) in the Verde Valley, Yavapai County, Arizona (after Carothers and Johnson 1971).

companies (e.g., Salt River Project and Wellton-Mohawk Irrigation District). However, researchers from a variety of disciplines in institutional and private research joined the rush to "improve water yields". Scientists and managers joined researchers from the U.S. Geological Survey, U.S. Forest Service, and innumerable colleges, universities, and other scientific institutions. These included: from the U.S. Geological Survey - Gatewood et al. (1950), Turner and Skibitzke (1952) Robinson (1958, 1965), Babcock (1968), Bowie et al. (1968), Thomsen and Schumann (1968), Culler et al. (1970); and from the U.S. Forest Service - Decker (1960), Horton (1960, 1966), Rich (1960, 1968), Gary (1962), Arnold (1968, 1972), Campbell and Green (1968). Papers from academia often discussed phreatophytes in a neutral sense as far as control philosophy, but their studies were often funded by vegetation management agencies. Academic, or combined, studies include Campbell and Dick-Peddie (1964) on the Rio Grande in New Mexico and Lindauer and Ward (1968) on the Arkansas in Colorado.

The date, 1968, which appears so often in phreatophyte publications is more than happenstance. This was the year during which activity peaked in phreatophyte control research and application. By 1970, several events regarding riverine management and research had taken place which made phreatophyte control difficult, especially for native species. They include:

(1) Increased conservation activities in regard to rivers, culminating in the Sierra Club's fight and victory over the Bureau of Reclamation in 1966, thereby preventing the construction of Marble Canyon and Bridge Canyon Dam on the Colorado River in Grand Canyon (Nash 1973).

(2) A series of environmental laws and Executive Orders affecting riverine management:

(a) Wilderness Act 1964
(b) Federal Water Project Recreation Act 1965
(c) Wild and Scenic Rivers Act 1968
(d) National Environmental Policy Act (NEPA) 1969

(3) A growing body of knowledge regarding the values of riparian (phreatophyte) habitat to wildlife, water quality, and recreational activities. For example, the fact that southwestern riparian habitats support the highest density of noncolonial nesting birds in the United States was first presented by Carothers and Johnson at the annual American Ornithologists Union meeting in Fayetteville, Arkansas in 1969; the information was later published (Carothers et al. 1974).

In 1968, the 12th Annual Arizona Watershed Symposium featured a panel, entitled, "Phreatophyte Control Pro and Con." This was a definite change from past symposia where papers were almost all pro control. The paper on wildlife values was presented by Bristow (1968), an

early leader in "wildlife rights for phreatophytes". Subsequent symposia often have papers related to watershed values other than increasing water yields. By 1970, the word phreatophyte was considered problematic enough that the Pacific Southwest Interagency Committee changed the name of its Phreatophyte Subcommittee to Vegetation Management Subcommittee, as though closing out the chapter for a single use value in watershed management. Since, two phreatophyte bibliographies have been published (Horton 1973, Paylore 1974) while the U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station published a research paper by Horton and Campbell (1974) entitled "Management of Phreatophyte and Riparian Vegetation for Maximum Multiple Use Values"). This does not mean that there are no longer those who would manage watersheds, including river systems, strictly for maximum water yield at the expense of other values. However, responsible managers do manage for maximum multiple use values, including recreation for a rapidly growing population.

Urbanization and Flood Control

Many of the activities associated with urbanization are detrimental to riparian ecosystems. This includes a vast array of projects ranging from the replacement of vegetation by buildings, streets, and parking lots, to channelization, and dams and levees for flood control.

These flood control programs often include structural as well as nonstructural methods in attempts to control or reduce the volume of floods. One of the most successful nonstructural projects we have seen may be found at Indian Bend Wash in central Arizona. This project, directed by the U.S. Army Corps of Engineers, has converted a frequently flooded section of Scottsdale, Arizona, into a greenbelt composed of attractive channels, holding lakes, and recreational parks. During floods, the channels and lakes serve to divert water into the nearby Salt River. Between floods, the system serves as an aesthetic, pleasant outdoor urban recreation area (personal observations).

Contrary to the information disseminated by many water salvage and flood control agencies, there is a growing body of knowledge indicating that many of the structural (dams, levees) flood control methods are not only ineffective, but many actually exacerbate flooding. In a study of flooding on the Mississippi River, Belt (1975) stated "constriction of the river channel causes flooding and makes floods higher; thus navigation works and levees cause significant rises in the stages of floods". Belt also discussed additional studies showing increased flooding due to structural features on the Missouri and other rivers.

In our experience, too, some of the practices which are often promulgated as flood control activities are ineffective, at best. Phreatophyte control projects (removal of streamside vegetation) are claimed to reduce flooding (Warskow 1967). To date, this claim has not been documented or quantified. In the Verde Valley of central Arizona mature cottonwoods were removed from the streambank during 1967-1969, thereby eliminating prime riparian wildlife and recreational habitat. This project, initiated by the Salt River Project, was designed to prevent flooding of private land. At the same time, it was proposed that by leaving some of the trees wildlife habitat would be preserved, indeed, even enhanced (Arnold 1972). Our observations over a period of several years after the phreatophyte control indicate the flood waters did indeed flow faster through these plots, with lower peaks than previously. However, loss of trees also seemed to allow greater soil erosion on the floodplain and the relatively few remaining trees were more easily washed out and measured wildlife use decreased proportionately (Carothers et al. 1974). In addition, downstream landowners complained of increased erosional loss of prime riverfront land from increased water velocity.

Some of the same arguments, pros and cons, just discussed also apply to channelization. In effect, channelization includes removal of most, if not all, streamside vegetation and subsequent ditching of the stream to prevent the natural overbank flow during high runoff periods. Natural overbank flows are a common and necessary feature of stream ecology, however when homes or businesses or agricultural fields are positioned in the floodplain, efforts are frequently made to control the stream. Again, we know of few studies addressing the effects of these projects in the western United States. Carothers and Johnson (1975b) surveyed breeding avian populations along two channelized southwestern streams (Gila River and Tonto Creek, Arizona) and found more than twice as many species and two to four times the number of birds on non-channelized vs. channelized plots of the same size and same habitat.

Most channelization projects are evaluated for effects on fish and other aquatic organisms. Only recently have studies of effects on riparian wildlife been assessed, even for streams in the eastern United States. Studies which show a reduction in riparian wildlife populations in channelized areas include Arner et al. (1976) and Prellwitz (1976).

Aquatic and riparian ecosystems are inextricably linked. In the same sense that recent studies have demonstrated that aquatic projects (e.g. channelization) affect riparian organisms, we find that riparian projects commonly affect aquatic ecosystems. A study by Stone (1970) in Central Arizona demonstrated that removal of cottonwoods along the Verde River, Oak Creek, and West Clear Creek had a severe detrimental effect on the existing fishery and the habitat had deteriorated to such an extent that it was impossible to establish a new fishery in the cleared areas. This was essentially

the same conclusion drawn by Carothers and Johnson (1971) regarding breeding birds. In addition to providing food for early settlers fishing has long been a favorite recreational pastime. More recently, bird watching, camping and other nonconsumptive activities have become even more popular than fishing.

Other studies which have shown similar effects on fisheries include: from grazing - Kennedy (1977), Meehan et al. (1977), and Cope (1979); from logging - Levno and Rothacker (1967), Gibbons and Salo (1973), and Meehan et al. (1977); and from road construction - Meehan et al. (1977). The sum of deleterious effects of vegetation management and stream control in riparian habitat include:

(a) With removal of vegetation, shade is lost and the stream temperature rises.
(b) The cross section of the stream is changed from sharp, protective banks and overhangs to rounded, exposed banks.
(c) With no streambank vegetation, there is a decrease in riparian-contributed detritis, insects, and other organic material important to aquatic ecosystems.
(d) There is usually an increase in concentrations of sediments and salts due to increased bank erosion, lower water quality and suitability for fish, water consumption and recreation.

Irrigated and urbanized areas may or may not be detrimental to wildlife and recreation, depending on several factors. A study in the suburbs of Tucson, Arizona, by Emlen (1974) showed a great increase in avian populations compared to original desert conditions (Table 2). Desert suburban areas become artificial riparian habitats due to watering of yards and planting of usually exotic yard plants. On the other hand, Carothers and Johnson (1975a) found a decrease in avian populations in mature cottonwood forests of the Verde Valley after urbanization occurred. The data suggest that if water is taken into the desert (e.g., expansion of urban areas) wildlife values increase; however if natural riparian areas are converted into urban areas, wildlife values decrease significantly. Recreational centers in urban and suburban areas commonly support artifical riparian habitats. These consist of parks, gardens, golf courses and other facilities, often with running streams or lakes.

Some water control projects can be designed to be compatible with water quality standards, wildlife values and outdoor recreational opportunities. Agricultural and urban developments, through use of greenbelts and floodplain zoning, can also protect many natural values. The current overuse of structural water controls and inadequate systems management or land use planning results in chaotic activities and loss of important socioeconomic and natural values. It is clear that many of the currently used water management techniques are ineffective, or even detrimental through worsening floods and water losses while, at the same time, causing the loss of the other values we have discussed. Benefit/cost ratios of much less than 1.0 accrue from many of these projects when costs figures are added for the socioeconomic activities discussed above.

Other Impacts on Riparian Resources

Mature riparian forests have suffered heavy damage from human activities. Much of this loss is due to grazing and consequent lack of regeneration as well as a reduction in water due to water management projects such as water storage, channelization, and phreatophyte and flood control. Other causes include cutting of timber for buildings, mines, corrals, fence posts, firewood for homes and smelters; and even fuel for streamships on the Colorado River (Ohmart et al. 1977). In 1860, while exploring Big Bend with camels, Lt. Echols wrote (fide Maxwell 1968), "The river has a fine valley on each side, about twenty-five miles down; more timber and wood than a post can use". This was near Castolon, now a ranger station on the Rio Grande in Big Bend National Park. Very few trees remain along that river today. This has greatly reduced the recreational and wildlife values of the National Park, necessitating the planting of cottonwoods in campgrounds. Most reaches of the river banks are treeless, covered by a nearly impenetrable mass of brush, including Tamarix and other exotic species.

Thus, impacts on riparian ecosystems range from simple practices such as fur-trapping for beaver (Castor canadensis), to the complex practices of attempting to increase water yields, often termed "water salvage", and problems associated with agriculture and urbanization.

THE SANTA CRUZ VALLEY: A CASE HISTORY OF RIVERCIDE

As one stands along the banks of a healthy river, a river with a high ecological diversity of aquatic life, clean water and an attendant, well developed riparian forest, it is virtually impossible to imagine the forces necessary to destroy that system. It can well be done however-done over a relatively short period of time through a variety of consumptive use practices. The Santa Cruz River of Tucson, Arizona is a prime example of what can happen to a healthy river through misuse, and we characterize its demise here.

As mentioned previously, missions were often built on rivers. San Xavier del Bac was no exception. In 1700, the cornerstone for the mission was laid south of an Indian village called Tucson on the banks of the Santa Cruz River. In 1776, the Spanish moved the presidio of Tubac north along the Santa Cruz to Tucson (Faulk 1970).

Table 2.--Comparison of breeding bird densities in selected habitats in the western United States (after Johnson 1978).

Habitat type	Location	Estimated Pairs/100 acres (40 ha)
NonRiparian		
Alpine Tundra		
Spruce-fir Timberline[1]	Wyoming	15-17
Conifer Forest		
Fir, Pine, Aspen[1]	Arizona	253
Spruce-Douglas Fir[1]	Arizona	380
Ponderosa Pine[1]	Arizona	336
Temperate Woodland		
Pinyon-Juniper[1]	Arizona	33
Encinal (Oak)[1]	Arizona	224
Grassland		
Temperate Grassland[1]	Arizona	64
Short Grass Prairie[1]	Wyoming	99-115
Desert Scrub		
Chihuahuan Creosotebush[1]	New Mexico	9-18
Sonoran Paloverde/Saguaro[1]	Arizona	105-150
Riparian and Wetland		
Riparian Deciduous Forest		
Mixed Broadleaf[1]	Arizona	332
Cottonwood[1]	Arizona	1059
Cottonwood[2]	Colorado	676
Cottonwood Floodplain[3]	N. Dakota	177
Temperate Riparian Woodland		
Ash-Cottonwood Draw[3]	N. Dakota	174
Ash-Elm Hardwood Draw[3]	N. Dakota	205
Mixed Mesophtic Canyon Bottom[3]	New Mexico	110
Woodland Along Prairie Stream[3]	Kansas	129
Subtropical Woodland (Bosque)		
Sonoran Desert Mesquite[1]	Arizona	476
Chihuahuan Desert Mesquite[1]	New Mexico	756
Temperate Marshland		
Cattail Marsh[1]	Arizona	175
Marsh[1]	California/Arizona	215-283
Cultivated and Urban Lands		
Urban (Artificial Riparian)[1]	Arizona	615
Cottonwood[1]	Arizona	605

[1]For source see Johnson 1978.

[2]Bottoroff 1974. Densities originally given as number pairs/km^2. Densities per 40 ha obtained by dividing total by 0.4.

[3]VanVelsen 1980. Densities originally given as number birds/km^2. Densities per 40 ha obtained by dividing total by 0.4. The remainder was then divided by 2.0 to obtain number of pairs.

For an arid land settlement, Tucson was fortunate; it had not just one flowing river, but two. Ft. Lowell was constructed on the south banks of the second stream, Rillito Creek, in 1873. A story which we have been unable to document tells of an excerpt from the log of a soldier stationed in Tucson in which he compared the fishing of Rillito Creek with the Santa Cruz. As incredible as the tale may seem to today's Tucsonian angler, historic records support the soldier's tale as not only possible, but probable. Excerpts in the following pages document the Santa Cruz as a fishing stream. The nearby San Pedro even supported a commercial fishery (Carothers 1977a). Tucson now has no perennial stream, with the Santa Cruz and Rillito Creek flowing only after local rains. The recreational value of a running stream or lake is incalculable to this desert city of almost 400,000 people. What happened to the lush, tree-lined Santa Cruz? The story can best be told through a series of excerpts from historical writings.

Let us draw a quick historical perspective of the area as viewed by some early ornithologists. The first record we have of an ornithologist's visit to the area was by Swarth (1905) during the summers of 1902 and 1903. He wrote:

> South of Tucson, Arizona, along the banks of the Santa Cruz River, lies a region offering the greatest inducements to the ornithologist. The river running underground for most of its course, rises to the surface at this point, and the bottomlands on either side are covered, miles in extent, with a thick growth of giant mesquite trees, literally giants, for a person accustomed to the scrubby bush that grows everywhere in the desert regions of the southwest, can hardly believe that these fine trees many of them sixty feet high and over, really belong to the same species. This magnificient grove is included in the Papago Indian Reservation, which is the only reason for the trees surviving as long as they have, since elsewhere every mesquite large enough to be used as firewood has been ruthlessly cut down, to grow up again as a straggly bush.

Willard (1912) later visited the area in 1911. He reported:

> The mesquite trees are wonders of their kind. There were some whose trunks, at the base, scaled over four feet in diameter. Meandering wood roads lead in every direction and one can never be quite sure that he is on the right one.

Dawson (1921) wrote of his visit to the area in 1917:

> A ruthless policy of deforestation, which was culminating at the time of our visit, has reduced its (the mesquite forest) heavier timber to about four-fifths of its former abundance and the destruction was going on, according to the Indian agent in charge, at the rate of 2,500 cords per annum. At that rate, the forest could not have held out above two years longer.

Apparently the roads mentioned by Swarth in 1912 had been the start of the deforestation program.

In 1940 Arnold wrote:

> Fortunately part of the area which we selected for the more detailed work and a rather extensive section immediately adjoining it more closely resemble the original condition as described by former writers. Here the mesquite attain a height of some twenty or twenty-five feet. They are of sufficient density to form a dense canopy of branches overhead during the summer season, and the ground is well covered with litter formed by the falling mesquite leaves. Trees 20-25 feet high are poor substitutes for the original stand with trees exceeding 60 feet in height.

An outstanding summary was written by Phillips et al. (1964):

> Particulary dramatic have been the changes along the valley of the Santa Cruz. This river originally flowed north to the San Xavier Indian Reservation, sank underground, and reappeared. It then flowed into Silver Lake, a pleasant cottonwood-shaded dam pond where persons from old Tucson could pass the time in boating and fishing ... Its water was used to run a mill ... During the early severe overgrazing, and extreme drought of 1892, conditions deteriorated so badly as to produce a raging flood that cut through and destroyed the dam at Silver Lake. The river became a continuous channeled affair without permanent bodies of water or marshes marking its course. Above Tucson the Papagos annually constructed an earthen dam with which to irrigate their field near San Xavier Mission. During the 1920's, this was replaced by a supposedly superior concrete dam, "Indian Dam," which promptly silted full. The Santa Cruz, however continued to flow below the dam and was diverted for irrigation. This flow finally ceased about 1945.
>
> Prior to World War II, the river at Sahuarita Butte (between Indian Dam and San Xavier Mission) was a paradise for birds. There were fine groves of cottonwoods, and, in the more open areas, thickets of batamote on the sandy bottoms back of the shallow channel itself.

Today "The Grand Mesquite Forest" looks like a depauperate thorn scrubland (Figure 8). To the problems caused by woodcutters, "progress" has added (a) a lowered watertable due to excess groundwater pumping for domestic and agricultural use; (b) additional erosion and habitat loss from increasing farming activities, and (c) Interstate 19 constructed longitudinally through the heart of the old forest, paralleling the Santa Cruz (Figure 9). The passing of the forest was accompanied by the death of most cottonwoods and other trees along the river. And, as one can easily guess, recreational values are nil while it is difficult to discuss water quality in a river which has ceased to flow. If the sad history of Santa Cruz River were an isolated situation, ecologists would not be waving so many red flags of alarm...it is not an isolated case, rather it is a typical perspective of how most Southwest streams and rivers have "evolved" under the stewardship of past consumptive use practices. It is clear, that the riparian and free flowing

Figure 8A.--Photograph (June 1942) of the Santa Cruz River near Tucson, Pima County, Arizona, looking south from Sahuarito Butte (now called Martinez Hill), elevation 2850 feet. Riparian vegetation is dominated by a cottonwood forest in the foreground and dense mesquite bosque (woodland) in the background. (Courtesy of David E. Brown, Arizona Game and Fish Department).

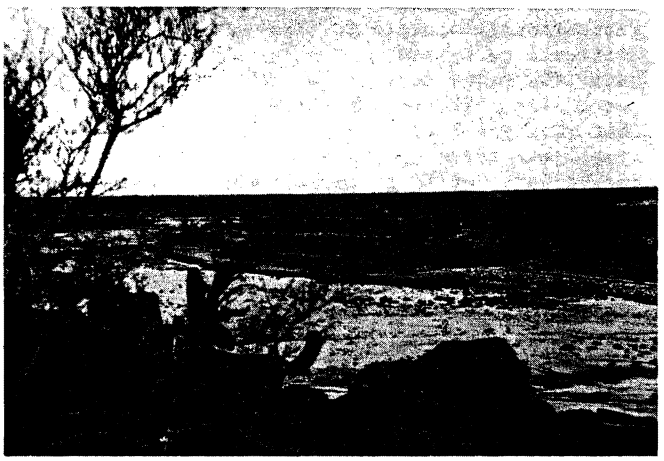

Figure 8B.--The same view (June 1981) of the Santa Cruz River from Sahuarito Butte. Note the increased width of the sandy channel, high eroded banks, absence of cottonwood trees, and scattered mesquite as compared to Figure 8A. Rip-rapped approach to the Interstate-19 bridge can be seen at middle right. (Courtesy of Raymond M. Turner, U.S. Geological Survey).

aquatic systems that remain must be given the most cautious protection.

THE IMPORTANCE OF RIPARIAN HABITATS TO RECREATION: SOCIOECONOMIC VALUES AND CONSUMPTIVE vs. NONCONSUMPTIVE RECREATION

Recreational activities are often divided into consumptive and nonconsumptive uses. In riparian habitats, consumptive uses include fishing, hunting, and other activities which actually remove natural resources. This may be contrasted with nonconsumptive uses, whereby the recreationists do not remove resources from their environment while engaging in activities such as birdwatching, camping, hiking, boating, and river running. However, nonconsumptive uses can lead to loss of resources if allowed in excess.

Figure 9A.--Santa Cruz River near Tucson, Pima County, Arizona; looking towards Sahuarito Butte. Riparian vegetation in the center of the photograph is dominated by cottonwood. Note bulldozer tracks in the foreground. Photograph from a 1940 U.S. Fish and Wildlife Report by Johnson A. Neff, "Third Progress Report on a Study of the White-winged Dove (Melopelia asiatica mearnsi)." (Courtesy of David E. Brown, Arizona Game and Fish Department.)

Figure 9B.--Same view along the Santa Cruz River looking toward Sahuarito Butte. In this June 1981 photograph, riparian vegetation is virtually absent and has been replaced by an Interstate-19 bridge. (Courtesy of Raymond M. Turner, U.S. Geological Survey.)

On a regional basis, the socioeconomic influence of consumptive vs. nonconsumptive recreational demands on riparian habitats are difficult to assess. Hunting and fishing were once the major form of outdoor recreation in the United States, but there is no question that this trend is changing. At present, only about one-fifth of the total U.S. population purchases hunting licenses, while about one-fourth purchase fishing licenses (USDI Fish and Wildlife Service 1977).

Non-consumptive recreation pursuits are rapidly becoming significant considerations in local, state and regional economics. In a recent study in Arizona, for example, Martin et al. (1974) found that over 60 percent of the recreational consumer surplus values was for nonconsumptive recreation. This study demonstrated the following total net benefits for recreation in Arizona during 1970 as:

Hunting	$34,480,315
Fishing	64,374,326
Nonconsumptive[1]	114,000,000

Both consumptive and nonconsumptive recreation are disproportionately greater in river valley systems than any other general area or habitat type. Studies by Sublette and Martin (1975) in the Salt-Verde River Basin of central Arizona placed a 1972 consumer surplus value of approximately $50 to $60 million on recreation in an area comprising only 12% of the State's potential recreational area. This unusually large value is probably due in part to the proximity of metropolitan Phoenix to this basin. Water based recreation is in such heavy demand in this desert metropolis that it boasts (unsubstantiated though it may be) of having one of the larger concentrations of boats/capita for the United States. More than 20,000 recreationists (Tonto National Forest files) can be found on some weekend days along a stretch of approximately five miles of the Salt River and its riparian environs near Phoenix.

"Tourism and travel" is one of the four major sources of income in Arizona, generating more than $4 billion in 1979 (Valley National Bank of Arizona 1980). Riverine (impounded) lakes and riparian areas receive a disproportionately large percentage of use by visitors. The most heavily visited outdoor areas within the State are rivers, including Grand Canyon National Park on the Colorado River (receives more than 40% of National Park area visitors), Lake Havasu State Park on the Colorado River (receives approximately 40% of State Park area visitors), and Glen Canyon and Lake Mead National Recreation Areas, on the Colorado River on Arizona's border (approximately 8-9 million visitors annually, receiving almost as many visitors as all of Arizona's other National and State Park areas combined). In recent years, there has been an ever increasing number of enthusiasts seeking the nonconsumptive recreational experience of "birdwatching". Every experienced birder knows that the greatest number of species and the highest density of birds can be found in riverbottom habitats.

Nineteen of 20 (95%) randomly selected Christmas Bird Counts for the inland United States in 1974 (National Audubon Society 1975) included streamside and/or lakeside vegetation. Of 166 species of birds nesting in the Southwest lowlands, 45% are restricted to riparian habitat and an additional 26% prefer it (Johnson et al. 1977). The socioeconomic importance of birdwatching can, in part, be quantified in local areas. A recent U.S. Fish and Wildlife publication (McNatt et al. 1980) evaluated use of three riparian areas in the Southwest by wildlife observers. This nonconsumptive, rural outdoor recreation usage generated approximately $12,370/acre for 440 acres during 1978. In regards to consumptive use, an estimate of over $41/acre of riparian habitat was made for nesting doves, based on hunting expenditures and total acreage of suitable nesting habitat.

As with "birdwatching", the recent increase in recreationists pursuing the sport of "river running" has become an important socioeconomic factor influencing management policies for streams and rivers and their associated riparian habitats. Regional synthesis of economic factors influenced by the increase in river recreation demands since the early 1970's (Huser 1977, Parent and Robeson 1976) indicate a multimillion dollar industry with no apparent decline in sales growth in sight. A further indication that nonconsumptive recreational pursuits are being increasingly oriented toward flowing water systems is the volume of literature that has appeared within the past five years dealing specifically with river recreation management (Anderson et al. 1980). This literature indicates that once recreational use has reached or exceeded area carrying capacity, even the nonconsumptive uses cause short and long term damage to overused habitats. It is clear however, that the relatively recent popularization of recreational demands on rivers and riparian areas is the single most important factor in motivating the management agencies to reduce the consumptive uses (grazing, agriculture, phreatophyte control, urbanization in floodplains) of the resource. As the nonconsumptive users become an important economic constituency, the agencies charged with the stewardship of streams and rivers and their associated habitats have economic justification for preserving an area for its "natural" values.

[1]Martin et al. (1974) used the term general rural outdoor recreation-picnicking, camping, hiking, swimming, boating, birdwatching and skiing (all but the last, skiing, are most often provided by riparian or impounded riverine areas).

RECREATION USES AND ASSOCIATED IMPACTS ON RIPARIAN HABITATS

Although we clearly see the increase in recreational use of free flowing aquatic systems and riparian habitats as being an important factor in preserving the remaining habitats, recreationists can cause rather serious ecological and management problems. The following section summarizes the known recreation related impacts to streams, rivers and their associated habitats and the state-of-the-art knowledge for mitigating these impacts.

The use of riparian habitats by persons seeking nonconsumptive recreational experiences can be functionally separated into two categories of use or special interest pursuit. These categories are; 1) land based recreation and 2) water based recreation. Further, the relative impact of recreational usage is a function of 1) specific visitor use patterns; 2) density; 3) temporal periodicity of use; 4) presence or absence of management scenarios allowing specific measure of resource protection; and 5) the natural capacity of rivers and streams and their associated riparian communities for purging recreation impacts.

Land based vs. water based recreation

Though the actual physical impacts to the riparian habitats associated with the two interest categories can be similar, it is useful to distinguish between the groups and their methods of utilizing the riparian resources.

The land based recreation group pursues such activities as picnicking, camping, backpacking, hunting, birdwatching, and other uses where the recreational experience sought is directly related to the presence of the unique habitat differentiation between the streamside vs. adjacent areas. The specific features of the riparian community that attract the visitor can be as diverse as shade for the camper of picknicker (an extremely important component of attraction in arid and climatically extreme areas), increased diversity and density of wildlife for the hunter and naturalist, and availability of water for the backpacker.

In contrast to the land based user, the water based recreationist has only a secondary interest in the riparian habitats. The water based recreationist has as a primary pursuit the experiences gained through utilizing the actual water corridor as a transportation/recreation route. Through land use statistics in general, reflecting ever increasing numbers of recreationists invading all outdoor areas, it can be seen that the use of water corridors for leisure activities has been increasing at a disproportionately high rate (see Figure 10). River recreation has increased so rapidly in the past 10 years that the pursuit has fostered the birth of a new multimillion dollar river

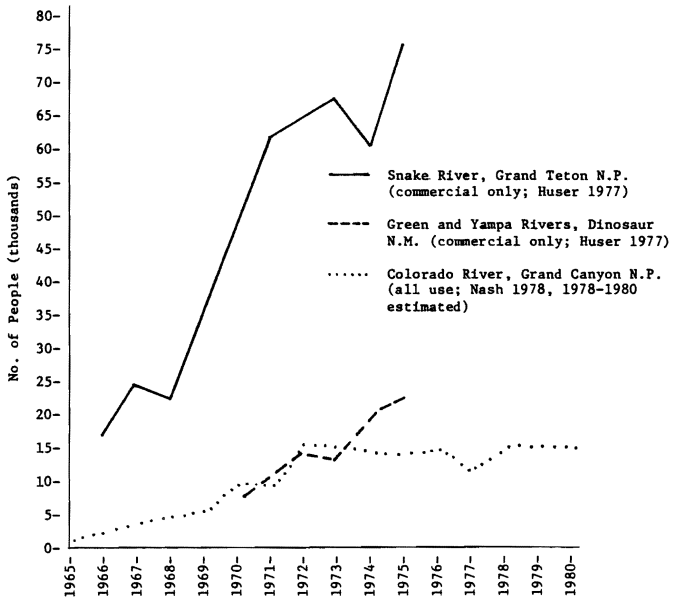

Figure 10.--Increase in the use of western river systems by whitewater recreationists, 1965-1980.

recreation industry (Huser 1977, Parent and Robeson 1976) while forcing land managers to confront problems of rapidly degrading environments and conditions of recreational overcrowding (Lewis and Marsh 1977). Concommitant with the increase in use of streams and rivers and the secondary impacts to their associated habitats, has come the above mentioned ecological awareness that some riparian communities contain floras and faunas richer in density and diversity than any other habitats known to man (Carothers et al. 1974, McNatt et al. 1980, USDAFS 1977).

The Complex Problem

It is primarily due to the relatively recent increases in river recreation use that land managers and researchers alike began to address the problems of identifying and quantifying the impacts recreationists have on riparian habitats and water quality. The recent literature dealing with the subject of river recreation is replete with studies attempting to establish baseline values for environmental quality along the most popular streams and rivers throughout the United States (see Appendix B for relevant literature on Rocky Mountain States). Also, the problem has exemplified the need for sociological studies specifically related to river recreation use (Heberlein 1977, de Bettencourt and Peterson 1977). One of the major related issues presently concerning recreation managers is the conflict which can occur between various resource uses. For instance, situations arise where one group of recreationists visit riparian areas for specific hunting or fishing experiences only to find their capture/bag success directly interferred with by river runners or other sportsmen. The crowding-conflict issue falls primarily within the realm of sociological carrying

capacity problems and will not be dealt with here.

Pivotal to our concerns are the actual physical and biological impacts recreationists, in general, have on the quality of the riparian environment. As more and more people utilize a particular riparian area, it becomes possible to measure the influence of visitation activities on soils, vegetation, animal communities, water quality, and in limited instances, air quality. Though the impacts of land based and water based recreation are virtually the same, it is important to note that the recent increase in river recreation has allowed numbers of recreationists to penetrate deeply into previously isolated riparian systems. When analyzing impacts to natural resources, all available evidence indicates that at some level of human use, permanent and adverse changes will take place with the system (Carothers, Colorado River Monitoring reports, Grand Canyon National Park files). The key to resource protection is for management to adjust use to a level at or below which the natural environmental quality of the system is not impaired. That is, an adjusted use level below the area's carrying capacity. Carrying capacity determinations are one of the most intriguing problems facing land managers today. Recent studies have clearly demonstrated that recreationally influenced damage to riparian ecosytems can be related to a variety of factors, some of which can be manipulated through innovative management plans without necessarily decreasing the total amount of use. Most impacts are initially related to increasing visitor usage (USDAFS, Marnell et al. 1978). However, when specific use patterns are analyzed and evaluated relative to the known environmental damage (Dolan et al. 1974, Carothers and Aitchison 1975, Carothers 1978) certain impact mitigation can alleviate the damage while providing justification for use levels to actually increase. Finally, and perhaps most importantly, the significance of impacts is directly related to the capacity a riparian system has for recovering from visitation damage through natural purging processes. Thus, if a drainage system has sufficiently variable discharge levels and the land-water interface is subject to seasonal displacement, concentration of human activities will migrate accordingly. That is, during high water recreational activities are displaced inland while during low flows usable areas increase in availability closer to the river of stream. In these systems, use patterns are distributed over a relatively large area and the fluctuating land-water interface affects a functional removal of certain recreational impacts.

In contrast, however, are riparian areas subject to natural steady state discharges (some springs and temperate mountain riparian systems) where recreational areas are relatively permanent and uninfluenced by stream discharge. The same concentration of use patterns can also occur along rivers and streams where structural controls (dams, aquaducts and levees) have altered natural flow patterns. Nowhere has the interrelationship between river structural control and acceleration and degree of recreational impacts reached greater proportions than along the Colorado River in Grand Canyon National Park. Without the presence of Glen Canyon Dam 15 miles upstream of the eastern boundary of the National Park, resource managers would have virtually no problem with recreational impacts to the riparian systems of the Colorado River. With the construction and operation of Glen Canyon Dam, the river within Grand Canyon was dramatically changed. The attractiveness of the area to recreationists increased (more predictable flow levels, sediment free water), while the system's capacity for purging recreation related impacts decreased (control of overbank floods, elimination of annual removal and redeposition of alluvial deposits).

Impact Analysis

Most available literature on recreation impacts in uncontrolled or relatively natural riparian ecosystems comes from analyses generated by recreation/habitat studies performed in the East and Midwest. Impacts in western riparian habitats are similar, allowing us to present a general overview of the variety of frequently permanent, adverse environmental changes resulting when carrying capacity has been exceeded. Where the state-of-the-art knowledge includes mitigation of specific impacts, these techniques or controls are detailed. The problems associated with recreation impacts in Grand Canyon are presented as a case history of a major riparian system that has been modified by structural control.

Soils

Impacts of concentrated recreational activities on soils only becomes critical on permanent substrates located above the normal high water discharge of the associated stream. Temporary substrates, that is, hydrologically dynamic gravel and sand bars can withstand tremendous pressures from the recreationist while sustaining virtually inconsequential changes to the ecosystem. It is the very nature of the stream land-water interface to undergo periodic change with fluctuating discharge. Once the human traffic becomes frequent on the "permanent"[2] substrate of the flood plain, a variety of impacts to soils can occur. In a recent review of the problem, Settergren (1977) listed the most common recreational impacts on soils as follows:

1) surface soil compaction,

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[2]"Permanent" here refers to that portion of the floodplain receiving high water so infrequently that a riparian vegetative community has developed; that is, the area outside the influence of scouring floods.

2) reduction in vegetative ground cover,

3) reduction in infiltration and hydraulic conductivity,

4) reduction in soil organic detritus, and

5) increase in soil density.

The overall consequences to the ecosystem stability of the above changes in the soil component are primarily denudation of vegetative cover through loss of water and nutrients and the subsequent increase in potential for erosion of the substrate.

Investigating the influence of recreationists in riparian areas where permanent campgrounds have been constructed outside the zone of high water influence in southern Arizona, Post (1979) found extreme conditions of soil deterioration. The soil had been damaged to such an extent that the limited area rainfall could not be absorbed. Post (1979) found that "...total pore space in the surface 5 cm. was 41-46% in the heavily used areas in the campground, and 60-71% in the undisturbed areas adjacent to the campground. This particularly affected the aeration as a percentage of large pores ranged from 17-28% in the campground to 42-50% in the undisturbed areas. Water intake rates averaged 2.5 cm. per hour in the campground and 28 cm. per hour in the undisturbed areas." Marnell et al. (1978), investigating recreational impacts on soils in the Ozark National Scenic Riverway, found average cubic foot weight of soils on heavily used areas to range from 135-140 lbs while control sites yielded value of 64-84 lbs; they also discuss total denudation, root exposure and increased erosion in response to visitor use.

The mass wasting downslope of Colorado River beach sediments as a result of human foot traffic has reached unusual proportions in Grand Canyon National Park. Valentine and Dolan (1979) have demonstrated that the combination of heavy recreational pressures and hydroelectric dam regulated river discharges may result in eventual complete erosion of a substantial number of alluvial terraces and available campsites. The dam controlled discharges on the Colorado River in Grand Canyon are virtually sediment free. As human activity loosens the beach substrate and gravity carries the sediments downslope to the river, the substrate is forever lost from the system. Valentine and Dolan (1979) estimate that in heavily used campsites, approximately 4.6m^3 of sand are lost annually (Table 3).

Further, it has been demonstrated that in the remaining Colorado River alluvial deposits, the concentration of human debris (litter, feces, charcoal from fires) can, at a minimum, reach significantly unaesthetic proportions (Carothers 1980), if not provide the potential for outright health problems (Knudsen et al. 1977, Phillips and Lynch 1977).

Table 3.-- Sediment displacement affected by recreational activities on Colorado River beaches in Grand Canyon. (After Valentine and Dolan 1979).

UPHILL STEP:	252 gm X 7 cm = 1764 gm-cm
DOWNHILL STEP:	96 gm X 5 cm = 480 gm-cm
NUMBER OF PEOPLE PER RAFT TRIP:	25
OVERNIGHT STOP:	10 trips up and down the beach per person
LUNCH STOP:	2 trips per person
CALCULATIONS:	
12 steps up per trip X 10 trips	=120 steps up
12 steps down per trip X 10 trips	=120 steps down
120 steps up X 25 people per night	=3000 steps up per night
120 steps down X 25 people per night	=3000 steps down/night
3000 steps up per night X 1764 gm-cm/step up	=52.9 X 10^5 gm-cm/night
3000 steps down per night X 480 gm-cm/step down	=14.4 X 10^5 gm-cm/night
Total	=67.3 10^5 gm-cm/night

BEACH OCCUPIED 150 NIGHT PER YEAR:

67.3 X 10^5 gm-cm/night X 150 nights/year = 1 X 10^9 gm-cm/year
+ 2 X 10^8 gm-cm/year due to lunch stops
= 12 X 10^8 gm-cm/year (1 gm = .385 ml = .385 cm^3 = 3.85 X $10^{-7}m^3$)
12 X 10^8 gm-cm/year X (3.86 X 10^{-7}) m^3/gm
= 460 m^3 moved 1 cm per year
or, equivalently, 4.6 m^3 moved 1 m per year

TOTAL SEDIMENT LOSS:

4.6 m^3 X 50 beaches = 230 m^3 moved 1 m per year.

Mitigation of Soils Impacts

General mitigation procedures dealing directly with improving deterioration in soil structure include the following:

1) initial positioning of campsites or use zones in areas where soil profiles can withstand visitor traffic (Settergren 1977),

2) rest rotation of use areas and identification of sensitive areas (Craig 1977),

3) actual physical aeration and fertilization of previously impacted areas (Post 1979), and

4) establishing threshold capacity or limits on use levels (Marnell et al. 1978).

In Grand Canyon innovative mitigation has been remarkably successful in partially restoring fouled campsites. Carothers (1977b) developed a waste disposal system for river recreationists that eliminated the disposal of over 60,000 lbs. of feces in beach sands each year. Other carryout guidelines and disposal policies on organic garbage and gray water have also reversed the trend of continual campsite degradtion. One of the most important improvements, however, has resulted from the National Park Service policy on the use of fires in riverine habitats. In the absence of debris purging floods, campsites were beginning to fill with nearly indestructible charcoal and ash. Although charcoal and ash are relatively inert substances, and cause no known physical or biological impact to either recreationists or the environment, the beach sands were becoming darker each year with the accumulation of campfire residue. In addition, driftwood supplies to fuel the fires was becoming scarce (USDI-NPS 1980). By initiating a policy of fire restriction during summer months and only allowing winter fires when contained in a fire pan or box where the residue could be collected and carried out, the Park Service effectively cleaned their beaches while allowing increases in visitor use.

Vegetation

Vegetational changes resulting from concentrated recreational use are generally the result of 1) direct physical or mechanical injury or 2) physiological responses to alterations in edaphic parameters (see "soils" section above).

The specific impacts resulting from concentrated visitor use in the riparian system, as taken from Manning (1979), Marnell et al. (1978), La Page (1967), Schmidley and Ditton (1978) and Settergren (1977) are as follows:

1) a reduction in density and diversity of herbaceous ground cover,

2) a decline in tree vigor (usually directly related to soil compaction and/or root dieback),

3) total elimination of seedlings and younger age classes of trees,

4) infection of mature trees with disease and/or parasites (direct result of mechanical injury),

5) a shift in species diversity favoring the proliferation of recreation tolerant species, and

6) invasion of exotic species either as a direct result of camping activities (watermelon, tomatoes, oats, rye, pineapples, marijuana, sprouting from seeds or cuttings) or habital alterations favoring the proliferation of exotic plants.

Though the above points present a consensus of the impact concentrated recreational use has on riparian habitats and vegetational profiles in general, there are no long-term studies published, or to our knowledge, in progress, that assess human use vs. riparian vegetation impact. Even in non-riparian areas where use presents substantial problems to vegetation management concerns, there are few long-term analytical studies (see Cole 1979 and Weaver et al. 1979 for review).

Most research on vegetation impacts from recreation use indicates that most measurable changes on nonriparian recreation sites result from initial, light use, while continual or increased use inflicts little additional damage (Cole 1979, LePage 1967). Weaver et al. (1979) found that grassland habitats have a greater tolerance to trampling than forb or tree species, and that deterioration of all species increases when the use area is on a slope. Since most riparian habitats are located upslope from the streambed, this information serves to point out that one might expect relatively high rates of deterioration with minimal use in some riparian areas.

In riparian habitats along the Rio Grande River in Texas, Schmidley and Ditton (1979) found significant correlations between per cent cover of trees and human use levels. Interestingly, their data seem to contradict the assumption held for nonriparian areas that once a threshold of impact has been reached, increased use causes no further damage. It seems logical to assume that trees would be especially vulnerable in heavily used riparian campgrounds since they are often the only source of fuel once driftwood supplies have been exhausted. In heavily forested nonriparian areas, fuel wood increases in supply as one moves away from the campground... in ripar-

ian areas, the "forest" is usally a very narrow band and in heavily used areas. Living trees are often the only remaining source of fuel (personal observations). Schmidley and Ditton (1979) did not find correlations with other species (grasses, forbs, and shrubs) and recreation use, in fact, and assessment of random points in riparian campgrounds did not reveal any differences in total ground cover between use areas and control sites.

In the Ozark National Scenic Riverways, Marnell et al. (1978) found that the average number of species of grasses, forbs, and shrubs decreased significantly from control sites (12) to low intensity use (7) to high intensity use (4). Marnell et al. (1978) also demonstrated that the younger age classes of trees were reduced or eliminated on moderately and heavily used visitation sites. Post (1979) was able to show correlations between restricted growth of riparian oak trees (Quercus sp.) and soil compaction.

In the unique dam altered riverine environment in Grand Canyon National Park, investigators have recently concentrated on the impacts recreationists inflict on the vegetative community (Carothers and Aitchison 1976, Carothers et al. 1979). These studies present an ironic data set for interpretation by resource and recreation management personnel of Grand Canyon National Park. With the presence of Glen Canyon Dam effectively regulating the annual peak discharge, scouring floods no longer sweep the channel. This has resulted in the proliferation of woody riparian species in areas that were annually inundated during the predam regime (Figure 12). This vegetation consists largely of the exotic salt cedar Tamarix chinensis, however the native species arrowweed Pluchea sericea, seep willow Baccharis spp., and true willows Salix spp. are locally co-dominants.

The woody vegetation has replaced the annual fast growing species that could set seed and reproduce in the intervening dry spells between peak discharges (see Turner and Karpisack 1980, and Figure 11). The relatively recent proliferation of woody riparian species has yet to equilibrate; that is, there is an interesting "habitat partitioning" developing between exotic and native species that begs further investigation. Interestingly, it has been suggested (Carothers et al. 1979) that if it were not for the trampling activities of recreationists (river runners and hikers) in portions of the riparian community (Zones 3 and 4, Figure 12B), many popular beach campsites would be overgrown with the "new" vegetation. Thus, recreationists are essentially carving their own campsite "niche" out of the rapidly growing, dam created vegetative community. Park managers have found it necessary to actively encourage projects where certain areas are "pruned" (Johnson 1977). Although this situation contains an interesting irony, it has also been demonstrated by Carothers et al. (1979) that once the visitor moves outside the

Figure 11.-- Salt cedar (Tamarix chinensis scrub on the Colorado River 2 miles (3.2 km) downstream from Glen Canyon Dam, Coconino County, Arizona, elevation 3150 feet. Glen Canyon National Recreation Area contract personnel tri-annually evaluate popular recreation areas for human related resource impacts. (Courtesy of Barbara Phillips.)

"new" riparian community, damage to the pre-dam habitats is severe (Zones 1 and 2, Figure 12B). In many areas along the Colorado River problems exist with multiple trailing (Figure 13), effecting the destruction of native species while encouraging the rapid growth and dissemination of exotic species.

Mitigation of vegetation impacts

One of the most common themes currently being emphasized as a means by which effective mitigation of vegetation impacts can take place implies a "plan ahead" attitude toward recreation management. That is, "vegetational changes resulting from recreational impacts will vary with vegetation type due to the susceptibility of habitats and species assemblage to alteration" Cole (1979). Thus, managers are encouraged to a) determine the effects of various use configurations on different vegetation types and b) concentrate recreational activities in areas where the least amount of impact will occur. Under this type of planning scenario, localized impacts can be more effectively managed through proper design and location of facilities rather than by restrictions and regulated use.

Since recovery rates for vegetation impacts are so slow to take place relative to the destruction rates, some investigators (Weaver et al. 1979, Cole 1979) see rest-rotation as only a dilution of the problem, not a solution.

In Grand Canyon riparian habitats, the destruction of vegetation by multiple trailing is being reduced by trail construction crews blocking secondary and unnecessary trails, while improving primary trails. In other

ZONE 1--Typical Vegetation (Desert), Uninfluenced by River Regime (Stable Community)

ZONE 2--High Flood Zone Woody Vegetation Prosopis, Acacia, Cercis, Celtis (Stable Community)

ZONE 3--Ephemeral Plant Zone, Periodically Scoured (Unstable Community)

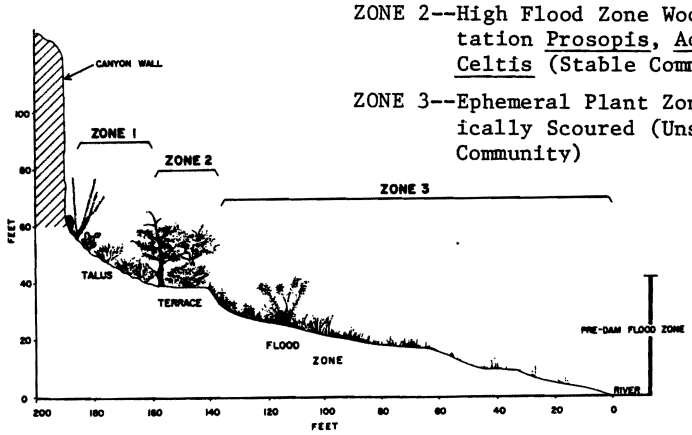

Figure 12A. A profile of the vegetative zones of the Colorado River floodplain in the Grand Canyon prior to the construction of Glen Canyon Dam. After Carothers et al. 1979.

ZONE 1--Typical Vegetation (Desert) Uninfluenced by River Regime (Stable Community)

ZONE 2--High Flood Zone Woody Vegetation Prosopis, Acacia, Cercis, Celtis (Stable Community)

ZONE 3--Zone of Short Lived Invasion Species Alhagi, Salsola, Descurainia, Bromus, Festuca (Unstable Community)

ZONE 4--New Riparian Zone - Tamarix, Salix, Pluchea, Baccharis (Rapid Proliferation)

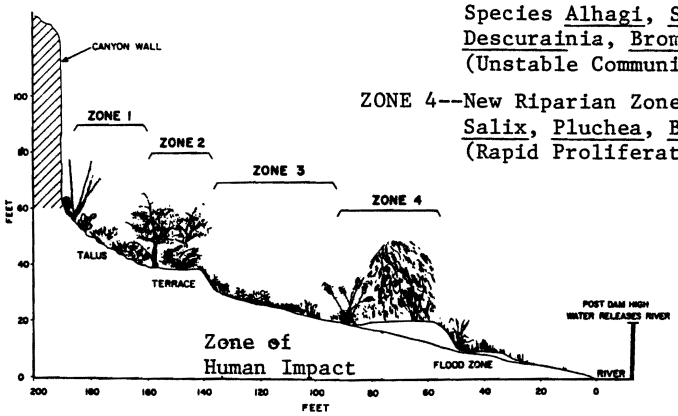

Figure 12B. A profile of the vegetative zones of the Colorado River floodplain in the Grand Canyon 13 years after the impoundment of Colorado River waters by Glen Canyon Dam. After Carothers et al. 1979.

cases, where possible, the hiker is routed out of the more sensitive riparian areas into adjacent upland habitats.

Wildlife

It is not our intention that this section deal with the impact of hunting on wildlife species. Rather, our analysis has focused on the habitat influences recreationists possibly have on the reproductive success and population structure of nongame species. For the purposes of this document, we adopt the game management assumption that individual wildlife species removed during hunting are surplus, and that this recreational activity has no long-term impact on riparian species.

Few data are available on the influence recreationists have on the population structure of riparian wildlife communities, in general, or special interest species, in particular. For the most part, assessment of the riparian habitat wildlife community is yet an uncompleted inventory task. Wildlife biologists are still involved in the primary task of identifying the various types of riparian communities and the local and regional importance of these areas to wildlife elements. In the Southwest,

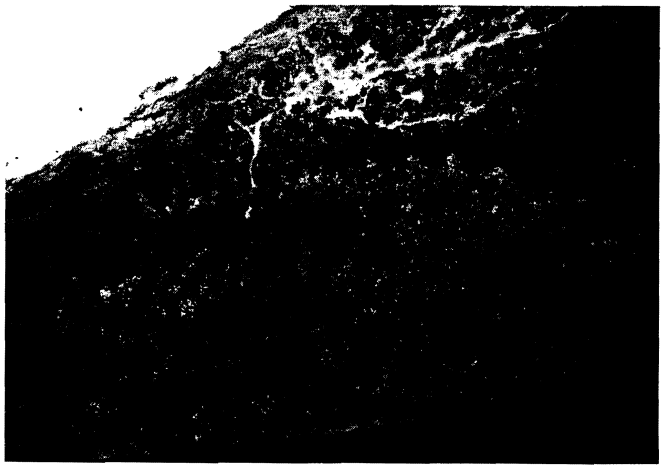

Figure 13.--Aerial view of Colorado River recreation site. 2 miles (3.2 km) downstream from Glen Canyon Dam. Recreationists have "carved out" the vegetation-free area in top center of the photograph creating a "bedroom effect." Salt Cedar (Tamarix chinensis) invaded the area after Glen Canyon Dam reduced peak river flow levels. (National Park Service photograph.)

it has been exceedingly difficult to find sufficiently large expanses of riparian vegetation where baseline values of vegetation/wildlife interactions could be studied. More often than not, riparian habitat-wildlife investigations have been in response to some major manipulative action on the habitat (see Sections on watershed and vegetative management, and urbanization and flood control). The impacts of concentrated recreation activity on these environments has been largely ignored while biologists and managers have been preoccupied with the seemingly more relevant pursuit of attempting to thwart the incessant disappearance of the riparian type. The many consumptive forces responsible for the destruction of riparian habitats are totally unrelated to most recreational activities.

Marnell et al. (1978) found no evidence that recreationists were directly impacting any riparian species. They were, however, concerned that some endangered cave species were susceptible to impact should visitation in their area of concern increase. Marnell's findings, in this case from the Ozark Mountains of Arkansas, would not necessarily be applicable in the very different habitats of our region. However, the methodology for studies such as this may be useful for our area.

There are a few studies that have attempted to quantify the interactions between riparian wildlife communities and recreation activities. Aitchison (1977) studied breeding bird densities and diversities in Forest Service campground areas in and adjacent to canyon hardwood riparian habitats. The study began before the campground was opened for public use, and continued throughout the breeding season after the campers arrived. Aitchison's (1977) results show a unique response from the avian community to the incidence of concentrated recreational activities. After three breeding seasons, two major recreationally related influences on the bird population were discerned: 1) although bird densities on the campground and control areas were similar before the campground opening date, the average weights of individuals occupying the campground shifted toward heavier species. That is, camper tolerant species (jays, robins, woodpeckers) remained, while smaller bodied, recreationally intolerant species (warblers, finches, wrens) departed; and 2) the population density and richness of species decreased in general when people began to occupy the area. Clearly, inhabitation of the campground by people caused an immediate and direct reduction in the number and kinds of breeding birds.

Investigating small mammal populations in heavily used campgrounds in Yosemite National Park, Foin et al. (1977) found a significant increase in one rodent species (Peromyscus maniculatus). The population demography of his species also showed a structure that had a greater proportion of juveniles when compared with areas that had no human visitation. Boeer and Schmidley (1977) studying riparian areas along the Rio Grand in Texas, found no significant difference in total rodent densities as a result of human activity; however, they observed the same preponderance of juveniles in the population. Boer and Schmidley (1977) suggest that human activities have discouraged predators from occupying the campground areas and the component of the rodent population that is usually most susceptible to predation (the juvenile) enjoys a relative level of protection.

Along the Colorado River in Grand Canyon, Carothers et al. (1979) observed several levels of influence vistors were effecting in the wildlife population. Their findings are as follows:

> The improper disposal of organic garbage and the intentional feeding of some of the "wild" animals have resulted in some striking changes in animal population densities and behavioral patterns. Heavily used campsites have higher densities of harvester ants (Pogonomyrex californicus) than lightly and moderately used campsites. Because of their painful and toxic sting this species presents a source of great discomfort and potential health hazard. The flesh fly (Sarcophagidae) and blow fly (Calliphoridae) populations show corresponding population increases at heavily used camping areas. Not only a source of discomfort and annoyance, but these species could become a source of fly-vectored disease. Increases in these insect populations

have also resulted in increases in certain vertebrates, such as some species of lizards which are found in unusually high densities near dirty campgrounds. One of the more interesting consequences of human occupancy of the wilderness beaches of the Grand Canyon is that at two of the most heavily used beach areas, House Sparrows (Passer domesticus) have taken up residence. This species does not normally occur outside of urban areas, as it seems to need the presence of man as part of its habitat requirements. Four species of native mammals, spotted skunk (Spilogale putorius), ringtails (Bassariscus astutus), rock squirrels (Spermophilus variegatus), and mule deer (Odocoileus hemionus) and one species of bird, the Raven (Corvus corax) have experienced either increases in densities or demonstrated significant shifts in their behavioral patterns as a result of being purposely fed by river runners or hikers. In some cases, particularly with the deer and rock squirrel, the increased and easily available low quality food supply has resulted in population explosions which have left these animals in poor health. As a result, Park Managers are now finding it necessary to discuss control reduction programs for tame squirrels and deer.

Mitigation of Wildlife Impacts

The few wildlife impacts that can be attributed to recreation activity can be mitigated by a) when possible, effecting a concentration of activities in areas where minimal impact will take place and b) discouraging activities that directly influence behavioral patterns of various wildlife species (e.g., feeding animals, leaving garbage, direct nest disturbance, etc.). The latter can only be accomplished through user education programs, while the former is slightly more complicated. In the case of Aitchison's (1977) study, he recommended moving some popular use structures (tables, privies, etc.) a few meters away from the central riparian zone into the adjacent ponderosa pine forest. In other riparian areas, it is not possible to displace user activities outside the riparian zone and other controls are necessary. Further study on the relationships between permanent recreational facilities (*campgrounds, docks, nature trails,* etc.) and their local influences on wildlife is definitely warranted. Although data are limited, it appears that some desert riparian habitats are susceptible to significant changes in their fauna once campgrounds become established. The Gilbert Ray Campground west of Tucson is a perfect example of the influences concentrated recreational activities have on resident bird populations. Water only infrequently runs in the wash that bisects the campground. Nevertheless, the vegetation in and along the banks of the arroyo is influenced by the drainage and the ephemeral water and, thus, may be considered a desert riparian habitat. The availability of refuse and "handouts" has provided wildlife with an energy source that was previously unavailable; but more importantly, several water spigots have been placed for the campers. The effluent from each of these artificial springs has created an "oasis" in the desert. Animal numbers (birds and mammals) in the camground areas are 5-6 times greater than values determined for the surrounding desert (Carothers, personal observation). The relationship is similar to that reported by Emlen (1974) where he noted significant increases in desert bird densities with urbanization of the desert near Tucson. One is cautiously led to the supposition that riparian wildlife impacts resulting from habitat destruction could be partially mitigated by "replacement" of riparian habitats.

Water Quality

A considerable body of recent literature has furthered our understanding of the interrelatedness between the quality of stream or river water and the adjacent terrestrial habitats (see Bormann and Citceno 1979, and Schlosser and Karr 1980 for review). All available information indicates that the influences concentrated recreational activity in riparian habitats can have on water quality may be exceedingly limited. Other than a few "point source" incidences, recreationists cannot begin to influence stream water quality to the extent the system is affected by other land use patterns. When a watershed is subjected to grazing and/or farming, significant increases in siltation and organic pollutants are usually detected in associated streams, while recreational activities are far less easy to pinpoint as sources for changing stream water quality.

Several relevant investigations have pursued the relationship between concentrated recreational activities and water and sediment quality (Knudsen et al. 1977, McKee and Brickler 1977, and Phillips and Lynch 1977, Marnell et al. 1978, Brickler and Tunnicliff 1980). All of these studies indicate that recreationists have little influence on the bacterial concentrations in the water or sediment they potentially influence. Marnell et *al. (1978) followed groups of river recreationists* and monitored fecal coliform concentrations in a stream above and below points of swimming and other related activities, they found..."bacteria levels in the water were increased only slightly by concentrated swimming activity." The aforementioned study was finally able to show considerable recreationally related impact to stream water quality when 500 horses crossed the stream above the sampling station. For a short period of time,

water pollution exceeded by 10 times the recommended levels (Federal Water Pollution Control Administration) for primary contact. This was, however, a short-term phenomena, the effects of which disappear through time and distance downstream from the point source.

Detailed investigation in Grand Canyon (Brickler and Tunnicliff 1980) found"... no apparent association between Colorado River surface water quality and potential influences of tributary inflows on intensive recreation use river sites." The investigators were, however, able to determine certain sources of contaminants in the natural environment that could possibly cause distress to the unwary rereationist.

Air Quality

Recreational activities in riparian habitats have almost no impact on air quality. The exceptions occur when campfires become the source of local, short-term air quality deterioration, but these instances have no lasting effect on overall environmental quality. Campfires have been known to escape confinement with resultant wildfires causing considerable short-term pollution. This is discussed further in the section on "fire" below. Another exception is dust from ORV (Off Road Vehicle) activities but we have no quantifiable data addressing this problem.

Wildfire

Although fire is an important feature in most natural terrestrial ecosystems, recreationally related wildfires are usually detrimental. Few statistics are available to use on the frequency of the problem in other areas, but in Grand Canyon Carothers et al. (1979), in a three year period, reported 10 wildfires in the riparian vegetation of the Colorado River and its tributaries. All of the fires were caused by the careless incineration of toilet tissue. Impacts noted as a result of the wildfires include elimination of actual or potential wildlife breeding habitat or foraging areas, damage to cultural resources, and the invasion of non-native pioneer plant species when vegetation reoccurs. Since Grand Canyon managers adopted a carry out policy of human fecal wastes, the incidence of wildfires related to recreation dimished substantially. Destruction of habitat through careless use of fire is one of the only ways recreationists can cause substantial changes in the riparian habitat. Frequently, the associated wildfires are far removed from control personnel and equipment and only die out for lack of fuel. The largest of these fires in Grand Canyon has encompassed approximately 10 acres of habitat.

Off Road Vehicles

Additional recreational impacts in riparian habitat that clearly need investigation are related to off road vehicles (ORVs). Although this is not a great problem in Grand Canyon it certainly is in many other areas. Environmental damage from ORVs has been researched in nonriparian habitats. However, additional studies are needed which examine both the aquatic and riparian parameters of riverine ecosystems. Often ORVs follow stream courses, including ephemeral, intermittent, or perennial, and our preliminary observations indicate potential damage (Carothers, research contract Apache/Sitgraves National Forest, Arizona-New Mexico). Aquatic and terrestrial habitats may be damaged by ORVs through actual physical destruction of habitat (e.g., broken vegetation, disruption of stream substrate, etc.) or through habitat modification (e.g., soil compaction, increased turbidity of water, increased erosion of stream banks, etc.). Analysis of influences of ORVs on stream resources is of prime concern in areas currently under multiple-use management stewardship, however in a recent extensive review of off-road vehicle impacts on vertebrates Berry (1980) referred to only one riparian paper. Weinstein (1978) found that birds in riparian areas have "marked tendencies ... to move away from ORV use areas".

CONCLUSIONS AND SUMMARY

Riparian wetlands occur as ecotones between adjacent aquatic areas (when surface water is present) and the surrounding uplands. Riverine ecosystems are characterized by concentrations of water and nutrients and differential productivity of vegetation and wildlife relative to drier, upland habitats. The resultant, outstanding species richness and population densities of plants and animals in these unique ecosystems have been well established for the Rocky Mountain Region.

Riparian habitats are also some of the most threatened North American ecosystems. Compared to acreages present when European settlers arrived in the West, an estimated 30% to less than 5%, of various riparian habitat types remain (Swift and Barclay 1980). Often, the remaining habitat is in poor biological health due to grazing, agriculture, water and flood management, urbanization, and other human activities. In turn, recreational/wildlife values and water quality have diminished.

Only recently, the mismanagement of western rivers has been recognized as cause for alarm regarding impacts to native fish faunas (Minckley and Deacon 1968). Associated water quality, fish and wildlife, and recreational values have resulted in the enactment of several laws to help protect these values (U.S.

Committee on Merchant Marine and Fisheries 1977). However, it was not until the 1970s that the importance of riparian habitats to both water and land based recreation, as well as for fish, wildlife, and water quality values was well established.

Our extensive review of the literature shows large gaps in the state of the knowledge regarding riparian ecosystems. In addition, the management and protection of these sensitive habitats is still poorly administered. Legislation, Executive Orders, and Administrative policies have been used to protect other wetlands, such as: coastal zones, navigable rivers and other eastern rivers, swamps, lakes, etc. The reasons for lack of application of these means of protecting Western riparian ecosystems are complex. They include: (a) the difficulty of understanding the multiple socioeconomic and natural values of these areas; (b) shortages of management resources (manpower and money) due to higher priorities; (c) conflicting uses; and (d) the lack of a proper systems analysis approach to the problem.

The management of riverine systems is one of the most difficult resource problems facing us today. The task is probably equal in difficulty to the struggle to maintain clear air. Rivers, their riparian ecosystems, and the waters they transport cross political and agency boundaries; they are in great demand for a multitude of uses by almost everyone; and they are essential to the biological well being of an area.

There is a growing awareness of the problems confronting agencies charged with managing these complex ecosystems. This is evident from the increasing numbers of publications, workshops, and position papers (Johnson and McCormick 1978) on the subject. Still, this is not nearly enough. Resource management agencies entrusted with maintaining these valuable natural resources must continue to gather scientifically based information on which to base intelligent management decisions. Finally, managers must demonstrate an educated concern as well as a demonstrated ability to properly manage riparian ecosystems.

As recreational pressures on free flowing aquatic systems and riparian habitats has increased in recent years, a re-analysis of consumptive vs. non-consumptive resource allocation has been forced on management agencies. Demands on the riparian resource by recreationists have become important socioeconomic factors in land use planning and a certain measure of attention and protection has been recently focused on the riparian ecosystem.

Recreationists can and do damage the riparian and aquatic ecosystem once area carrying capacity has been reached and/or exceeded, however most recreational impacts can be mitigated through research/mitigation programs. This paper, however, is not designed to set the research/mitigation priorities necessary to effect proper management of riparian ecosystems. Various agencies conduct activities under specific legislative mandates but policies differ in different areas. It would, therefore, seem inappropriate to recommend the same research priorities for the USDA Forest Service, USDI Park Service, US Army Corps of Engineers, Bureau of Reclamation, etc.

Our discussions of the current status and impending human-caused problems in riparian ecosystems are sufficient to indicate research and mitigation needs to any agency, group, or individual responsible for riparian lands. This is especially true for the management of wildlife and recreational resources. Each individual agency must assume responsibility for the resources under its jurisdiction in order to prevent further degradation of riparian habitat. In too many areas further degradation will result in the complete loss of these valuable natural resources.

LITERATURE CITED

Aitchison, S. W. 1977. Some effects of a campground on breeding birds in Arizona. pp. 175-182. In R. R. Johnson and D. A. Jones (tech. coords.), Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Anderson, B. W., A. Higgins and R. D. Ohmart. 1977. Avian use of saltcedar communities in the Lower Colorado River Valley. pp. 128-136. In R. R. Johnson and D. A. Jones (tech. coords.), Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Anderson, D. H., E. C. Leatherberry and D. W. Lime. 1978. An Annotated Bibliography on River Recreation. USDA For. Serv. Gen. Tech. Rpt. NC-41, North Central For. Exp. Sta., St. Paul, Minn. 62 pp.

Arner, D. H., H. R. Robinette, J. E. Frasier and M. H. Gray. 1976. Effects of Channelization of the Luxapalila River on Fish, Aquatic Invertebrates, Water Quality, and Furbearers. USDI Fish and Wildl. Serv. FWS/OBS-76-08, Washington, D.C. 58 pp.

Arnold, L. W. 1940. An Ecological Study of the Vertebrate Animals of the Mesquite Forest. M.S. Thesis, Univ. Ariz., Tucson. 79 pp.

Arnold, J. F. 1968. Watershed planning. pp.

13-19. In Twelfth Annual Arizona Watershed Symposium. Ariz. State Land Dept., Phoenix. 49 pp.

Arnold, J. F. 1972. Ecology and management of riparian vegetation (abstract only). J. Ariz. Acad. Sci. (Proceedings Suppl. 16th Ann. Meeting) 7:20.

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

Babcock, H. M. 1968. The phreatophyte problem in Arizona. pp. 34-36. In Twelfth Annual Arizona Watershed Symposium. Ariz. State Land Dept., Phoenix. 49 pp.

Barr, G. W. 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 pp.

Behnke, R. J. 1979. Values and protection of riparian ecosystems. pp. 164-167. In G. A. Swanson (tech. coord.). The Mitigation Symposium: A National Workshop on Mitigating Losses of Fish and Wildlife Habitats. USDA For. Serv. Gen. Tech. Rpt. RM-65, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 684 pp.

Behnke, R. J., and R. F. Raleigh. 1978. Grazing and the riparian zone: impact and management perspectives. pp. 263-267. In R. R. Johnson and D. A. Jones (tech. coords.). Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D.C. 410 pp.

Belt, C. B., Jr. 1975. The 1973 flood and man's constriction of the Mississippi River. Science 189:681-684.

Berry, K. H. 1980. A review of the effects of off-road vehicles on birds and other vertebrates. pp. 451-467. In R. M. DeGraff (tech. coord.). Workshop proceedings: management of western forests and grasslands for nongame birds. USDA For. Serv. Gen. Tech. Rep. Int-86, Intermt. For. & Range Exp. Stn., Ogden, Ut., 535 pp.

Boeer, W. J., and D. J. Schmidley. 1977. Terrestrial mammals of the riparian corridor in Big Bend National Park. pp. 212-217. In R. R. Johnson and D. A. Jones (tech. coords.). Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.
Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Boldt, C. E., D. W. Uresk and K. E. Severson. 1978. Riparian woodlands in jeopardy on northern high plains. pp. 184-189. In R. R. Johnson and J. F. McCormick (tech. coords.). Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D. C. 410 pp.

Borman, F. H.,and G. E. Citceno. 1979. Patterns and Process in a Forested Ecosystem. Springer Verlag, New York, N. Y. 253 pp.

Bottorff, R. L. 1974. Cottonwood habitat for birds in Colorado. Amer. Birds 28:975-979.

Bowie, J. E., et al. Use of Water by Riparian Vegetation, Cottonwood Wash, Arizona. USDI Geol. Survey Water-Supply Paper 1858, U.S. Govt. Print. Off., Washington, D.C. 62 pp.

Brickler, S. K., and B. Tunnicliff. 1980. Water Quality Analyses of the Colorado River Corridor of Grand Canyon. College of Agriculture Paper 350., Univ. of Ariz., Tucson. 134 pp.

Bristow, B. 1968. Statement by Arizona Game and Fish Dept. on phreatophyte clearing projects. pp. 41-44. In Twelfth Annual Arizona Watershed Symposium. Ariz. State Land Dept., Phoenix. 49 pp.

Brown, D. E., C. H. Lowe, and C. P. Pase. 1979. A Digitized Classification System for the Biotic Communities of North America, with Community (Series) and Association Examples for the Southwest. J. Ariz. -Nev. Acad. Sci. 14 (Suppl. 1):1-16.

Brown, T. C., P. F. O'Connell and A. R. Hibbert. 1974. Chaparral Conversion Potential in Arizona - Part II: An Economic Analysis. USDA For. Serv. Res. Paper RM-127, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 28 pp.

Campbell, C. J., and W. A. Dick-Peddie. 1964. Comparison of phreatophyte communities on the Rio Grande in New Mexico. Ecology 45:492-502.

Campbell, C. J., and W. Green. 1968. Perpetual succession of stream-channel vegetation in a semiarid region. J. Ariz. Acad. Sci. 5:86-98.

Carothers, S. W. 1977a. Importance, preservation, and management of riparian habitats: an overview. pp. 2-4. In R. R. Johnson and D. A. Jones (tech. coords.). Importance, Preservation, and Management of Riparian Habitats: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky
In R. Ittner et al. (ed.), Recreational Impact on Wildlands. Proceedings of the

Conference. USDA For. Serv. Pacific Northwest Region Rpt. No. R-6-001-1979. 333 pp.

Carothers, S. W. 1977b. Let's carry it all out. Down River, August 1977.

Carothers, S. W. 1978. River Resource Monitoring Project, Grand Canyon National Park. Unpubl. Prog. Rpt., Grand Canyon Natl. Park, Ariz. 10 pp.

Carothers, S. W. 1980. River Resource Monitoring Project, Grand Canyon National Park. Unpubl. Prog. Rpt., Grand Canyon National Park, Ariz. 10 pp.

Carothers, S. W., and S. W. Aitchison (ed.). 1976. An Ecological Survey of the Riparian Zone of the Colorado River between Lees Ferry and the Grand Wash Cliffs, Arizona. Colorado River Tech. Rpt. No. 10, Grand Canyon Natl. Park, Ariz. 251 pp.

Carothers, S. W., S. W. Aitchison and R. R. Johnson. 1979. Natural resources, white water recreation, and river management alternatives on the Colorado River, Grand Canyon National Park, Arizona. pp. 253-259. In R. M. Linn (ed.), First Conference on Scientific Research in the National Parks, Vol. I. Proceedings of the Conference. USDI Natl. Park Serv. Trans. and Proceed. Series No. 5, Natl. Park Serv., Washington, D.C. 681 pp.

Carothers, S. W., and R. R. Johnson. 1971. A summary of the Verde Valley breeding bird survey. Proj. FW-16-10, Ariz. Game and Fish Dept. Land and Water Proj. Investigations, Phoenix. 20 pp.

Carothers, S. W., and R. R. Johnson. 1975a. Water management practices and their effects on nongame birds in range habitats. pp. 210-222. In D. R. Smith (tech. coord.), Symposium on Management of Forest and Range Habitats for Nongame Birds: Proceedings. USDA For. Serv. Gen. Tech. Rpt. WO-1, Washington, D.C. 343 pp.

Carothers, S. W., and R. R. Johnson. 1975b. The effects of stream channel modification on birds in the Southwestern United States. pp. 60-76. In R. V. Corning et al. (eds.), Symposium on Stream Channel Modification: Proceedings. Stream Channel Modification Symposium, Grottoes, Va. 172 pp.

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

Cole, D. N. 1979. Reducing the impact of hikers on vegetation: an application of analytical research methods. pp. 71-78.

Conn, J. S., D. A. Mouat and R. B. Clark. 1975. An Assessment of the Impact of Water Impoundment and Diversion Structures on Vegetation in Southern Arizona. Off. of Arid Lands Studies Bull. 11, Univ. of Ariz., Tucson. 84 pp.

Cope, O. B. (ed.) 1979. Grazing and Riparian/Stream Ecosystems. Proceedings of the Forum. Trout Unlimited Inc., Denver, Colo. 94 pp.

Coues, E. 1874. Birds of the Northwest: A Handbook of the Ornithology of the Region Drained by the Missouri River and its Tributaries. U. S. Geol. Survey of the Territories Misc. Publ. No. 3, U. S. Govt. Print. Off., Washington, D.C. 791 pp.

Craig, W. S. 1977. Reducing impacts from river recreation users. pp. 155-162. In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

Culler, R.C., et al. 1980. Objectives, Methods, and Environment-Gila River Phreatophyte Project, Graham County, Arizona. USDI Geol. Survey Prof. Paper 655-A, U. S. Govt. Print. Off., Washington, D.C. 25 pp.

Dawson, W. L. 1921. The season of 1917. J. Mus. Comp. Oology 2:27-36.

de Bettencourt, J. and G. L. Peterson. 1977. Standards of environmental quality for recreational evaluation of rivers. pp. 245-255. In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rep. NC-28, North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

Decker, J. P. 1960. A brief summary of the influence of phreatophytes on water yield in arid environments. pp. 64-69. In B. H. Warnock and J. L. Gardner (eds.). Water Yield in Relation to Environment in the Southwestern United States. Proceedings of the Symposium. Amer. Assn. Advancement Sci., Southwestern and Rocky Mtn. Div, Alpine, Texas. 74 pp.

DeGraff, R. M. (tech. coord.) Workshop proceedings: management of western forests and grasslands for nongame birds. USDA For. Serv. Gen. Tech. Rep. Int-86, Intermt. For. & Range Exp. Stn., Ogden, UT, 535 p. Collins, Colo. 217 pp.

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

Duisberg, P. C. (ed.). 1957. Problems of the Upper Rio Grande, An Arid Zone River. Proceedings of the Symposium. U.S. Comm. for Arid Resource Improvement and Development Publ. No. 1. 69 pp.

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

Emory, W. T. 1848. Notes of a Military Reconnaissance from Fort Leavenworth in Missouri to San Diego in California. Wendell and Van Benthvysen, Washington, D.C. 614 pp.

Faulk, O. B. 1970. Arizona: A Short History. Univ. of Oklahoma Press, Norman. 266 pp.

Ffolliott, P. F., and D. B. Thorud. 1974. Vegetation Management for Increased Water Yield in Arizona. Agr. Exp. Sta. Tech. Bull. 215, Univ. of Ariz., Tucson. 38 pp.

Foin, T. C., E. O. Garton, C. W. Bowen, J. M. Everingham and R. O. Schultz. 1977. Quantitative studies of visitor impacts on environments of Yosemite National Park California, and their implications for park management policy. J. Environmental Mgmt. 5:1-22.

Gary, H. L. 1962. Removal of tamarisk reduces water-table fluctuations in Central Arizona. USDA For. Serv. Res. Note RM-81, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 6 pp.

Gatewood, J. S., J. W. Robinson, B. R. Colby, J. D. Hem and L. C. Halpenny. 1950. Use of Water by Bottomland Vegetation in lower Stafford Valley, Arizona. USDI Geol. Survey Water-Supply Paper 1103, U. S. Govt. Print. Off., Washington, D.C.

Gibbons, D. R., and E. O. Salo. 1973. An Annotated Bibliography of the Effects of Logging on Fish of the Western United States and Canada. USDA For. Serv. Gen. Tech. Rpt. PNW-10, Pac. Northwest For. and Range Exp. Sta., Portland, Oregon. 145 pp.

Glinski, R. L. 1977. Regeneration and distribution of sycamore and cotton-wood trees along Sonoita Creek, Santa Cruz County, Arizona. pp. 116-123. In R. R. Johnson and D. A. Jones (tech. coords.). Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. USDA For. Serv. Res. Paper RM-117, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 23 pp.

Gregg, R. 1979. A method for analyzing livestock impacts on stream and riparian habitats. pp. 92-94. In O. B. Cope (ed.), Grazing and Riparian/Stream Ecosystems. Proceedings of the Forum. Trout Unlimited Inc., Denver, Colo. 94 pp.

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

Heberlein, T. A. 1977. Density, crowding, and satisfaction: sociological studies for determining carrying capacities. pp. 67-76. In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

Heede, B. H. 1976. Gully Development and Control: The Status of Our Knowledge. USDA For. Serv. Res. Paper RM-169, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 42 pp.

Hibbert, A. R., E. A. Davis and D. G. Scholl. 1974. Chaparral Conversion Potential in Arizona - Part I: Water Yield Response and Effects on Other Resources. USDA For. Serv. Res. Paper RM-126, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 36 pp.

Horton, J. S. 1960. Use of a Root Plow in Clearing Tamarisk Stands. USDA For. Serv. Res. Note RM-50, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 6 pp.

Horton, J. S. 1966. Problems of land management in the various phreatophyte zones. pp. 1-6. In Pacific Southwest Inter-Agency Committee Phreatophyte Symposium 66-3 Meeting, Rocky Mtn. For. and Range Exp. Sta., Tempe, Ariz. 57 pp.

Horton, J. S. 1973. Evapotranspiration and Water Research as Related to Riparian and Phreatophyte Management: An Abstract Bibliography. USDA For. Serv. Misc. Publ. No. 1234, Washington, D.C. 192 pp.

Horton, J. S. 1977. The development and perpetuation of the permanent tamarisk type in the phreatophyte zone of the Southwest. pp. 124-127. In R. R. Johnson and D. A. Jones (tech. coords.). Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo.217 pp.

Horton, J. S., and C. J. Campbell. 1974. Management of Phreatophyte and Riparian Vegetation for Maximum Multiple Use Values.

Huser, V. 1977. Industry responds to the explosion in river recreation. pp. 38-44. In River Recreation Management and Research. Proceedings of the Symposium.

USDA For. Serv. Gen. Tech. Rpt. NC-28. North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

Johnson, R. R. 1971. Tree removal along southwestern rivers and effects on associated organisms. pp. 321-322. Amer. Phil. Soc., Yearb. 1970.

Johnson, R. R. 1977. Synthesis and management implications of the Colorado River Research Program. Colorado River Tech. Rpt. No. 17, Grand Canyon Natl. Park, Ariz. 75 pp.

Johnson, R. R. 1978. The Lower Colorado River: a western system. pp. 41-55. In: R. R. Johnson and J. F. McCormick (tech. coords.). Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D. C. 410 pp.

Johnson, R. R., L. T. Haight and J. M. Simpson. 1977. Endangered species vs. endangered habitats: a concept. pp. 68-79. In Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Johnson, R. R., and J. F. McCormick (tech. coords.). 1978. Strategies for the Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D.C. 410 pp.

Kennedy, C. E. 1977. Wildlife conflicts in riparian management: water. pp. 52-58. In R. R. Johnson and D. A. Jones (tech. coords.). Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Knudsen, A. B., R. Johnson, K. Johnson and N. R. Henderson. 1977. A bacteriological analysis of portable toilet effluent at selected beaches along the Colorado River, Grand Canyon National Park. pp. 290-295 In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

LaPage, W. F. 1967. Some observations on campground trampling and ground cover response. USDA For. Serv. Res. Pap. NE-68. 11 pp.

Levno, A., and J. Rothacher. 1967. Increases in Maximum Stream Temperatures after logging in Old-growth Douglas-fir Watersheds. USDA For. Serv. Res. Note PNW-65, Pac. Northwest For. and Range Exp. Sta., Portland, Oregon. 12 pp.

Lewis, D. E., and G. G. Marsh. 1977. Problems resulting from the increased recreational use of rivers in the west. pp. 27-31. In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Cent. For. Exp. Sta., St.Paul, Minn. 455 pp.

Lindauer, I. E., and R. T. Ward. 1968. A Survey of the Woody Phreatophytes in the Lower Arkansas River Valley of Colorado. USDI Bur. Reclamation, Pueblo, Colo. 46 pp.

Lowe, C. H. (ed.). 1964. The Vertebrates of Arizona. Univ. Ariz. Press, Tucson. 270 pp.

Manning, R. E. 1979. Impacts of recreation on riparian soils and vegetation. Water Resour. Bull. 15:30-43.

Marnell, L., D. Foster and K. Chilman. 1978. River Recreation Research Conducted at Ozark Scenic Riverways 1970-1977: A Summary of Research Projects and Findings. USDI Nat. Park Serv., Van Buren, Missouri. 139 pp.

Martin, W. E., R. L. Gum and A. H. Smith. 1974. Demand for and value of hunting, fishing and general rural outdoor recreation in Arizona. Tech. Bull. 211, Agri. Exper. Sta., Univ. of Ariz., Tucson, Az. 56 pp.

Maxwell, R. A. 1968. The Big Bend of the Rio Grande: A Guide to the Rocks, Geologic History and Settlers of the Area, of B. B. Nat'l Pk. Bur. of Econ. Geol./ Univ. Texas - Guidebook 7. 138 pp.

McKee, P. C., and S. K. Brickler. 1977. Bottom sediment analysis of the recreational waters of upper Sabino Creek. In Hydrology and Water Resources in Arizona and the Southwest, School of Renewable Natural Resources, Univ. of Ariz., Tucson. 7:109-114.

McNatt, R., R. J. Hallock and A. W. Anderson. 1980. Riparian Habitat and instream flow studies, Lower Verde River. Fort McDowell Reservation, Arizona, June 1980. Riparian Habitat Analysis Group, Office of Environment, USDI Fish and Wildl. Serv., Albuquerque, N.M. 52 pp.

Meehan, W. R., F. J. Swanson and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular

reference to salmonid fishes and their food supply. pp. 137-145. In R. R. Johnson and D. A. Jones (tech. coords.), Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Meinzer, D. E. 1923. Outline of Ground-Water Hydrology, With Definitions. U. S. Geol. Surv. Water-Supply Pap. 494. U.S. Govt. Print. Off. Washington, D.C. 71 pp.

Minckley, W. L., and D. E. Brown. In press. Southwestern Wetlands In D. E. Brown (ed.), Biotic Communities of the Southwest. USDA For. Serv. Gen. Tech. Rpt., Rocky Mtn. For. and Range Exp. Sta., Fort Collins, Colo.

Minckley, W. L., and J. E. Deacon. 1968. Southwestern Fishes and the enigma of "endangered species." Science 159:1424-1432.

Moore, R. E. and W. A. Warskow. 1973. Brushy Basin - A Formula for Watershed Management Success. pp. 18-20. In Proceedings: 17th Annual Arizona Watershed Symposium, Ariz. Water Comm. Rpt. #5, Phoenix, Az. 40 pp.

Nash, R. 1973. Wilderness and the American Mind. Yale Univ. Press, New Haven, Conn. 300 pp.

National Audubon Society. 1975. The seventy-fifth Christmas bird count. Amer. Birds. 29(2):151-638.

Odum, E. 1959. Fundamentals of Ecology. W. B. Saunders Co., Philadelphia. 546 pp.

Odum, E. P. 1978. Opening address: ecological importance of the riparian zone. pp. 2-4. In R. R. Johnson and D. F. McCormick (tech. coords.) Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D.C.

Ohmart, R. D., W. O. Deason and C. Burke. 1977. A riparian case history: the Colorado River. pp. 35-47. In R. R. Johnson and D. A. Jones (tech. coords.), Importance, Preservation and Management of Riparian Habitat: A Symposium. USDA For. Serv. Gen. Tech. Rpt. RM-43, Rocky Mtn. For. and Range Exp. Sta., Ft. Collins, Colo. 217 pp.

Parent, C. R. M., and F. E. Robeson. 1976. An Economic Analysis of the River Running Industry in the Grand Canyon National Park. Colorado River Tech. Rpt. No. 16, Grand Canyon Natl. Park, Ariz. 131 pp.

Paylore, P. 1974. Phreatophytes - A Bibliography (Revised). USDI Off. of Water Resources Research, Washington, D. C. 277 pp.

Phillips, A., J. Marshall and G. Monson. 1964. The Birds of Arizona. Univ. Ariz. Press, Tucson. 212 pp.

Phillips, R. A., and C. S. Lynch. 1977. Human Waste Disposal on Beaches of the Colorado River in Grand Canyon. Colorado River Tech. Rpt. No. 11, Grand Canyon Natl. Park, Ariz. 79 pp.

Post, D. F. 1979. Soil Conditions on Campsite and Recreational Areas with Special Reference to Bonita Campground, Chiricahua National Monument in Arizona. Coop. Natl. Park Res. Studies Unit Tech. Rpt. No. 4, Univ. of Ariz., Tucson. 27 pp.

Potter, L. D. 1979. Ecology of shoreline vegetation, Lake Powell. pp. 247-252. In R. M. Linn (ed.), First Conference on Scientific Research in the National Parks, Vol. I. Proceedings of the Conference. USDI Nat. Park Serv. Trans. and Proceed. Series No. 5, Natl. Park Serv., Washington, D.C. 681 pp.

Powell, J. W. 1961. The Exploration of the Colorado River and Its Canyons. Dover Publ. Inc., New York. 397 pp. (Unabridged republ. of Flood and Vincent 1895 version, Canyons of the Colorado).

Prellwitz, D. M. 1976. Effects of Stream Channelization on Terrestrial Wildlife and Their Habitats in Buena Vista Marsh, Wisconsin. USDI Fish and Wildl. Serv. FWS/OBS-76/25, Wash., D.C. 64 pp.

Rich, L. R. 1960. Water yields from the brush and oak-woodland region of Arizona. pp.28-38. In B. H. Warnock and J. L. Gardner (eds.), Water Yield in Relation to Environment in the Southwestern United States. Proceedings of the Symposium. Amer. Assn. Advancement Sci., Southwestern and Rocky Mtn. Div., Alpine, Texas. 74 pp.

Rich, L. R. 1968. Preliminary Water Yields after timber harvest on Castle Creek, Arizona watersheds. pp. 9-12. In Twelfth Annual Arizona Watershed Symposium. Ariz. State Land Dept., Phoenix. 49 pp.

Robinson, T. W. 1958. Phreatophytes. USDI Geol. Survey Water-Supply Paper 1423, U.S. Govt. Print. Off., Washington, D.C. 84 pp.

Robinson, T. W. 1965. Introduction, Spread and Areal Extent of Saltcedar (Tamarix) in the Western States. USDI Geol. Survey Prof. Paper 491-A, U.S. Govt. Print. Off., Washington, D.C. 12 pp.

Schlosser, I. J., and J.R. Karr. 1980. Determinants of Water Quality in Agricultural Watersheds. Univ. of Illinois Water Resources Center Research Rpt. 147. 75 pp.

Schmidley, D. J., and R. B. Ditton. 1978. Relating human activities and biological resources in riparian habitats of western Texas. pp. 107-116. In R. R. Johnson and J. F. McCormick (tech. coords.). Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. WO-12, Washington, D.C. 410 pp.

Schmidley, D. J., and R. B. Ditton. 1979. Assessing human impacts in two national park areas of western Texas. pp. 139-152. In R. Ittner et al. (ed.), Recreational Impact on Wildlands. Proceedings of the Conference. USDA For. Serv. Pacific Northwest Region Rpt. No. R-6-001-1979. 333 pp.

Settergren, C. D. 1977. Impacts of river recreation use on streambank soils and vegetation--state-of-the-art knowledge. pp. 55-59. In River Recreation Management and Research. Proceedings of the Symposium. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Cent. For. Exp. Sta., St. Paul, Minn. 455 pp.

Shrupp, D. L. 1978. The wildlife values of lowland river and stream habitat as related to other habitats in Colorado. pp. 42-51. In W. D. Graul and S. J. Bissell (tech. coords.), Lowland River and Stream Habitat in Colorado: A Symposium. Colo. Chap. Wildl. Soc. and Colo. Audubon Council. 195 pp.

Smith, F. 1977. A short review of the status of riparian forests in California. pp. 1-2. In A. Sands (ed.), Riparian Forests in *California: Their Ecology and Conserva*tion. Proceedings of the Symposium. Inst. of Ecology Publ. No. 15, Univ. of Calif., Davis. 122 pp.

Stone, J. L. 1970. Cottonwood Clearance Program on the Verde River and Its Tributaries. Comp. Rpt. FW16-10, Fisheries Eval. of Salt River Proj., Ariz. Game and Fish Dept., Phoenix. 6 pp.

Sublette, W. J., and W. E. Martin. 1975. Outdoor Recreation in the Salt-Verde Basin of Central Arizona: Demand and Value. Univ. of Ariz. Agric. Exp. Sta. Tech. Bull. 218. 41 pp.

Swarth, H. S. 1905. Summer birds of the Papago Indian Reservation and of the Santa Rita Mountains, Arizona. Condor 7:22-28.

Swift, B.L., and J. S. Barclay. 1980. Status of Riparian Ecosystems in the United States. Unpubl. ms., USDI Fish and Wildl. Serv., Kearneysville, W. Va.; Paper Presented at the 1980 Amer. Water Resources Assn. Natl. Conf., Minneapolis, Minn. 29 pp.

Thomsen, B.W., and H. H. Schumann. 1968. Water Resources of the Sycamore Creek Watershed, Maricopa County, Arizona. USDI Geol. Survey Water - Supply Paper 1861, U.S. Govt. Print. Off., Washington, D.C. 53 pp.

Turner, R. M. 1974. Quantitative and Historical Evidence of Vegetation changes along the Upper Gila River, Arizona. USDI Geol. Survey Prof. Paper 655-H, U.S. Govt. Print. Off., Washington, D.C. 20 pp.

Turner, R. M., and M.M. Karpiscak. 1980. Recent vegetation changes along the Colorado River between Glen Canyon Dam and Lake Mead, Arizona. USDI Geol. Survey Prof. Paper 1132, U.S. Govt. Print. Off., Washington, D.C. 125 pp.

Turner, S. F., and H.E. Skibitzke. 1952. Use of water by phreatophytes in 2000-foot channel between Granite Reef and Gillespie Dams, Maricopa County, Arizona. Trans Amer. Geophys. Union 33: 66-72.

U.S. Committee on Merchant Marine and Fisheries. 1977. A Compilation of Federal Laws Relating to Conservation and Development of Our Nation's Fish and Wildlife Resources, Environmental Quality, and Oceanography. Serial No. 95-B, U.S. Govt. Print Off., Washington, D.C. 933 pp.

USDA Forest Service. 1977. River Recreation Management and Research. USDA For. Serv. Gen. Tech. Rpt. NC-28, North Central For. Exp. Sta., St. Paul, Minn. 455 pp.

USDI Fish and Wildlife Service. 1977. 1975 National Survey of Hunting, Fishing and Wildlife - Associated Recreation. USDI Fish and Wildl. Serv., Washington, D.C. 91 pp.

USDI National Park Service. 1980. Colorado River Management Plan, Grand Canyon National Park, Arizona. USDI Natl. Park Serv., Grand Canyon Natl. Park, Ariz. 36 pp.

Valentine, S., and R. Dolan. 1979. Footstep-induced sediment displacement in the Grand Canyon. Environmental Management 3:531-533.

Valley National Bank. 1980. Arizona Statistical Review. Valley Nat. Bank of Arizona, Phoenix, Arizona. 73 pp.

Van Hylckama, T.E.A. 1974. Water Use by Saltcedar as Measured by the Water Budget Method. U. S. Geol. Surv. Prof. Pap. 491-E. U.S. Govt. Print. Off., Washington, D.C. 30 pp.

Van Velsen, W. T. (ed.). 1980. Forty-third breeding bird census. Amer. Birds 34: 41-44.

Wagoner, J. J. 1949. The History of the Cattle Industry in Southern Arizona, 1540-1940. Unpubl. MA Thesis, Univ. of Ariz., Tucson. 252 pp.

Warnock, B. H., and J. L. Gardner (eds.). 1960. Water Yield in Relation to Environment in the Southwestern United States. Proceedings of the Symposium. Amer. Assn. Advancement Sci., Southwestern and Rocky Mtn. Div., Alpine, Texas. 74 pp.

Warskow, W.L. 1967. The Salt River Valley Water Users' Association's watershed rehabilitation program: a progress report. pp. 25-27. In Eleventh Annual Arizona Watershed Symposium. Ariz. State Land Dept., Phoenix. 38 pp.

Weaver, T., D. Dale and E. Hartley. 1979. The relationship of trail condition to use, vegetation, user, slope, season and time. pp. 94- 100. In R. Ittner et al. (ed.), Recreational Impact on Wildlands. Proceedings of the Conference. USDA For. Serv. Pacific Northwest Region Rpt. No. R-6-001-1979. 333 pp.

Weinstein, M. 1978. Impact of off-road vehicles on the avifauna of Afton Canyon, California. U. S. Bur. of Land Man., Calif. Desert Prog., Riverside, Calif., Rpt. on Contr. CA-060-CT7-2734.

Wigel, D. D. 1973. A Survey of the Nesting Habitats of the White-winged Dove in Arizona. Arizona Game and Fish Dept. Spec. Rpt. No. 2, 37 p.

Willard, F. C. 1912. A week afield in southern Arizona. Condor 14:53-63.

Woodbury, A. M. (ed.). 1959. Ecological Studies of the Flora and Fauna in Glen Canyon. Univ. of Utah Anthro. Papers No. 40 (Glen Canyon Series No. 7). 226 pp.

Woods, L. G. 1966. Multiple use management of mountain riparian vegetation. pp. 37-43. In Pacific Southwest Inter-Agency Committee Phreatophyte Symposium 66-3 Meeting, Rocky Mtn. For. and Range Exp. Sta., Tempe, Ariz. 57 pp.