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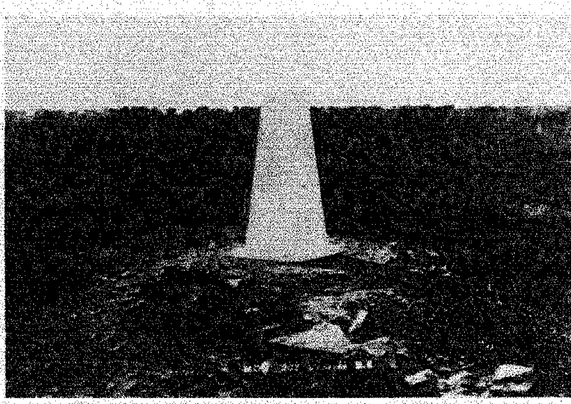
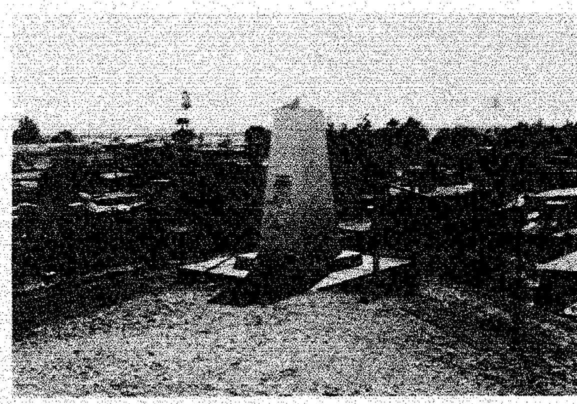
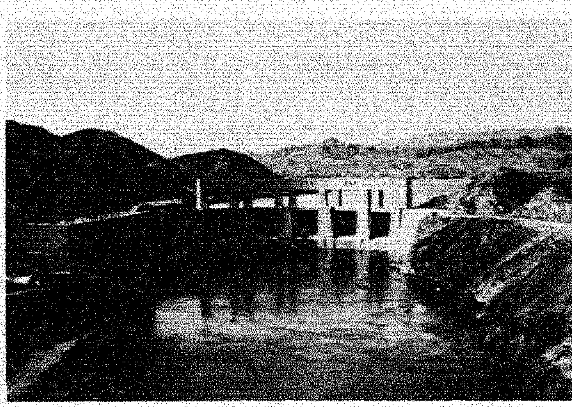
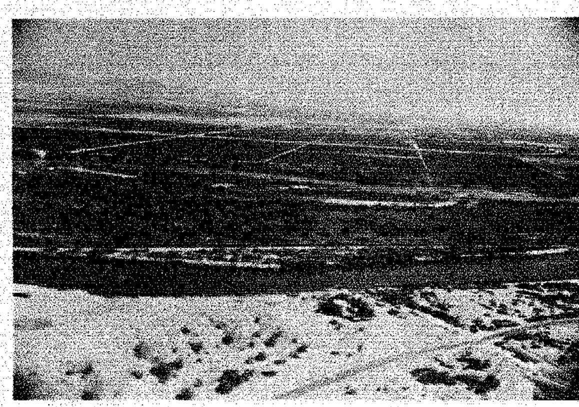
THE ECOLOGY OF THE LOWER COLORADO RIVER FROM DAVIS DAM TO THE MEXICO-UNITED STATES INTERNATIONAL BOUNDARY: A Community Profile









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THE ECOLOGY OF THE LOWER COLORADO RIVER FROM DAVIS DAM TO THE MEXICO-UNITED STATES INTERNATIONAL BOUNDARY: A COMMUNITY PROFILE

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PREFACE

This profile report covers the lower Colorado River system from Davis Dam in southern Nevada to the border of Mexico. It is a synthesis of all existing information, to the extent possible, describing the ecology of the lower Colorado River and its adjacent riparian ecosystem. In a sense, it is a historical as well as an ecological document. Historically, the flow of the river decided the nature of the ecology of the lower Colorado River. The lower Colorado River is presently completely controlled by a series of upstream impoundments that regulate the flow of the river. This control provides man with the opportunity to manipulate the river and its adjoining floodplain to an extent probably not realized on any other river system in the United States. As a consequence, there is little remaining of the "natural" systems that formerly flourished in and along the river prior to its settlement by emigrants of European descent. The river and its adjacent riparian borders are and will be what the citizens of the southwestern United States and, to some extent, the whole nation want it to be. This report will facilitate efforts of those managers, ecologists, politicians, and other interested participants in deciding what kinds of environment we want along the lower Colorado River.

The authors have tried to show how hydrology and vegetation formerly set the stage for fish and wildlife habitats and populations along the river, and how land and water use practices currently control fish and wildlife habitats and populations. The report is designed to provide the reader with easy access to information on a variety of subjects related to the hydrology and ecology of the river over time. There is some redundance for this reason; however, this decision was a conscious one to provide internal clarity within different sections of the report. Native floodplain vegetation, for example, is controlled by overbank flooding and groundwater, and is discussed in those terms. On the other hand, vegetation controls wildlife and it is also described in terms of wildlife habitat.

The senior author had overall responsibility for assigning subjects for review and synthesis and for integrating the various components of the report. Questions and comments on the technical and scientific contents of the report should be addressed to the authors. Requests for copies of the report should be addressed to:

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CONVERSION TABLE

Metric to U.S. Customary

Multiply	By	To Obtain
millimeters (mm)	0.03937	inches
centimeters (cm)	0.3937	inches
meters (m)	3.281	feet
kilometers (km)	0.8214	miles
square meters (m^2)	10.76	square feet
square kilometers (km^2)	0.3861	square miles
hectares (ha)	2.471	acres
liters (l)	0.2642	gallons
cubic meters (m^3)	35.31	cubic feet
cubic meters (m^3)	0.0008110	acre-feet
milligrams (mg)	0.00003527	ounces
grams (g)	0.03527	ounces
kilograms (kg)	2.205	pounds
metric tons (t)	2205.0	pounds
metric tons (t)	1.102	short tons
kilocalories (kcal)	3.958	British thermal units
Celsius degrees (C^o)	$1.8(C^o) + 32$	Fahrenheit degrees

U.S. Customary to Metric

Multiply	By	To Obtain
inches (inches)	25.40	millimeters
inches (inches)	2.54	centimeters
feet (ft)	0.3048	meters
fathoms	1.829	meters
miles (mi)	1.609	kilometers
nautical miles (nmi)	1.852	kilometers
square feet (ft^2)	0.0929	square meters
acres	0.4047	hectares
square miles (mi^2)	2.590	square kilometers
gallons (gal)	3.785	liters
cubic feet (ft^3)	0.02831	cubic meters
acre-feet (acre-ft)	1233.0	cubic meters
ounces (oz)	28.35	grams
pounds (lb)	0.4536	grams
short tons (ton)	0.9072	metric tons
British thermal unit (BTU)	0.2520	kilocalories
Fahrenheit degrees (F^o)	$0.5556(F^o) - 32$	Celsius degrees

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ACKNOWLEDGMENTS

We could not have begun to assemble this publication without past help and support of many individuals and agencies. The Bureau of Reclamation funded the lion's share of the work, but U.S. Fish and Wildlife Service, Bureau of Land Management, Arizona Department of Game and Fish, and California Department of Fish and Game monies also supported some studies.

We owe a deep appreciation and thanks to Bureau of Reclamation Regional Director, the late Mr. Ed Lundberg, for his foresight and environmental concern relative to bringing the Bureau into compliance with environmental laws. His Environmental Specialists, Mr. Phillip Sharpe and his staff, were supportive and encouraged us throughout our efforts. Our knowledge of this ecosystem would have been miniscule without their help and support.

To our many field biologists, secretaries, computer programmers, and others we express our deepest gratitude. Blood, sweat, tears, and time were unselfishly given by these dedicated people to help in learning and understanding more of this complex riparian ecosystem.

We would like to extend our appreciation to the following individuals for the logistical and editorial efforts: Judy Hohman, U.S. Fish and Wildlife Service; Dr. Gerald C. Horak, TGS Technology, Inc.; William G. Kepner, U.S. Fish and Wildlife Service; Robert Leidy, Environmental Protection Agency Project Officer, Region IX; W.L. Minckley, Arizona State University; Ed Pendleton, U.S. Fish and Wildlife Service; John Peters, Environmental Protection Agency; and Charles Segelquist, U.S. Fish and Wildlife Service.

Rough and final copies of the manuscript and most of the figures were prepared by Mrs. Cindy D. Zisner. Her word processing, editing, and illustrative skills are deeply appreciated, and were instrumental in completing the work. Any errors or omissions are the responsibility of the authors.

CHAPTER 1. INTRODUCTION

The Colorado River has played a major role in shaping the physical, biotic, and cultural history of a large portion of western North America. In the arid Southwest it is a permanent source of water in an otherwise arid environment. Its waters collect from melting snows and become heavily laden with sediments from the continent's interior. Ultimately, these sediments were deposited to form the delta at the Gulf of California when the river flowed under natural conditions.

An ecological description of the lower Colorado River system today cannot be made without discussing the drastic and rapid modification that the system has undergone during the last 150 years of human use. The Colorado River once inspired only explorers, geologists, and biologists. The modern river is now controlled and manipulated by politicians, lawyers, engineers, farmers, and recreationists who strive to harness its power, to irrigate desert lands, and otherwise make use of its water. The politics of water is a fundamental aspect of life in the Southwest today simply because water is vital to human existence in desert environments. This reality in itself has been detrimental to natural resources along the Colorado River within a relatively few years.

The lower Colorado River is one of the most manipulated ecological systems in North America. The taming of the lower Colorado River and changes in its faunal and floral diversity make it an important ecosystem to study. Therefore, this community profile of the lower Colorado River addresses both past and present ecological dynamics of the system. We attempt to outline present and future management problems on the lower Colorado River, based on community dynamics and prospective solutions to these problems.

This community profile is intended for use by a number of parties. Primarily, this document should encompass much of the general information on the past and present conditions of the river and its associated flora and fauna. We hope that the information included here is basic enough to be understood by the general public, and detailed enough for use by professional managers and researchers. Greater detail on issues and information presented here may be gained through the Literature Cited section of this document.

This first chapter defines the study area, its climate, and a brief discussion of the floodplain riparian vegetation, which constitutes a major focus of this profile. Chapter 2 summarizes a history of human occurrence in the lower Colorado River Valley, with general descriptions of documented floral and faunal changes. Chapter 3 describes the physical, chemical, and limnological nature of the aquatic environment, and also includes a brief discussion of the physicochemical nature of the terrestrial environment. Chapter 4 summarizes the extent of agriculture in the valley and the use of agriculture by wildlife. Chapter 5 discusses human uses of the valley, other than agriculture, and summarizes effects on the fauna of the system. Chapter 6 documents recent trends in riparian and marsh habitats on the lower Colorado River.

Chapters 7-12 describe the floral and faunal communities on the lower Colorado River. Chapter 7 provides a survey of the major plant species (including algae) found in both aquatic and terrestrial habitats. Similarly, Chapter 8 surveys the most important invertebrate species and communities again in both aquatic and terrestrial habitats. The vertebrate groups are surveyed separately, with Chapter 9 for fish, Chapter 10 for amphibians and reptiles, Chapter 11 for birds, and Chapter 12 for mammals. Use of habitats is detailed for all vertebrate species or groups of species wherever data are available. Species of special concern and those threatened or endangered are treated for each floral and faunal group in their respective chapters.

Chapter 13 provides an assessment of the health of the present-day Colorado River ecosystem. In this last chapter we describe means by which some elements of the natural system may be maintained or reestablished. We end with what we see are the prospects for the immediate future of the Colorado River ecosystem, given the present trends in management.

1.1 STUDY AREA DESCRIPTION

The study area is the lower reach of the Colorado River, which flows 453 km (281.5 mi) north to south from Davis Dam, near Bullhead City, AZ, to the Mexico-United States International Boundary at San Luis (Figure 1). The Colorado River originates from two main branches, the Green and the Grand (Colorado) Rivers, which drain the eastern Great Basin and the southern Rocky Mountains, respectively. The river's waters travel some 2,736 km (1,700 mi) and drop over 4,267 m (14,000 ft) in elevation before emptying into the Gulf of California in Mexico. Between the river's origins and the delta, the Colorado River forged many gorges and canyons, the most famous of which is the Grand Canyon. The lower Colorado River, below the Grand Canyon, establishes the present-day boundary of Arizona with Nevada, California, and Mexico. This lower stretch flows through a level and rather broad valley (Figure 2). Historically, it reached its mouth in a vast delta of alluvial silt beds, marshes, and forests. Today, the lower Colorado River encounters a series of major obstacles (Figure 3). In Arizona, the river flows through Glen Canyon Dam near the Utah-Arizona border, then through Hoover Dam below the Grand Canyon, and through a series of lesser dams to the south. Virtually all of the Colorado River's water is allocated and used by the seven states (Colorado, Wyoming, Utah, Nevada, New Mexico, Arizona, and California) that compose its watershed basin. The controlled flows rarely reach the Mexican border below Yuma, AZ, and, until recently, little or no water has reached the delta in three decades.

Although this region has been markedly altered by the placement of dams, an understanding of the natural events that shaped the floodplain is essential to understanding its present-day plant and animal life. Two noteworthy characteristics of the Colorado River were largely responsible for floodplain formation. One was the unusually large load of sediments carried by the river, contributing both to the erosive actions of the current and to the deposition of large

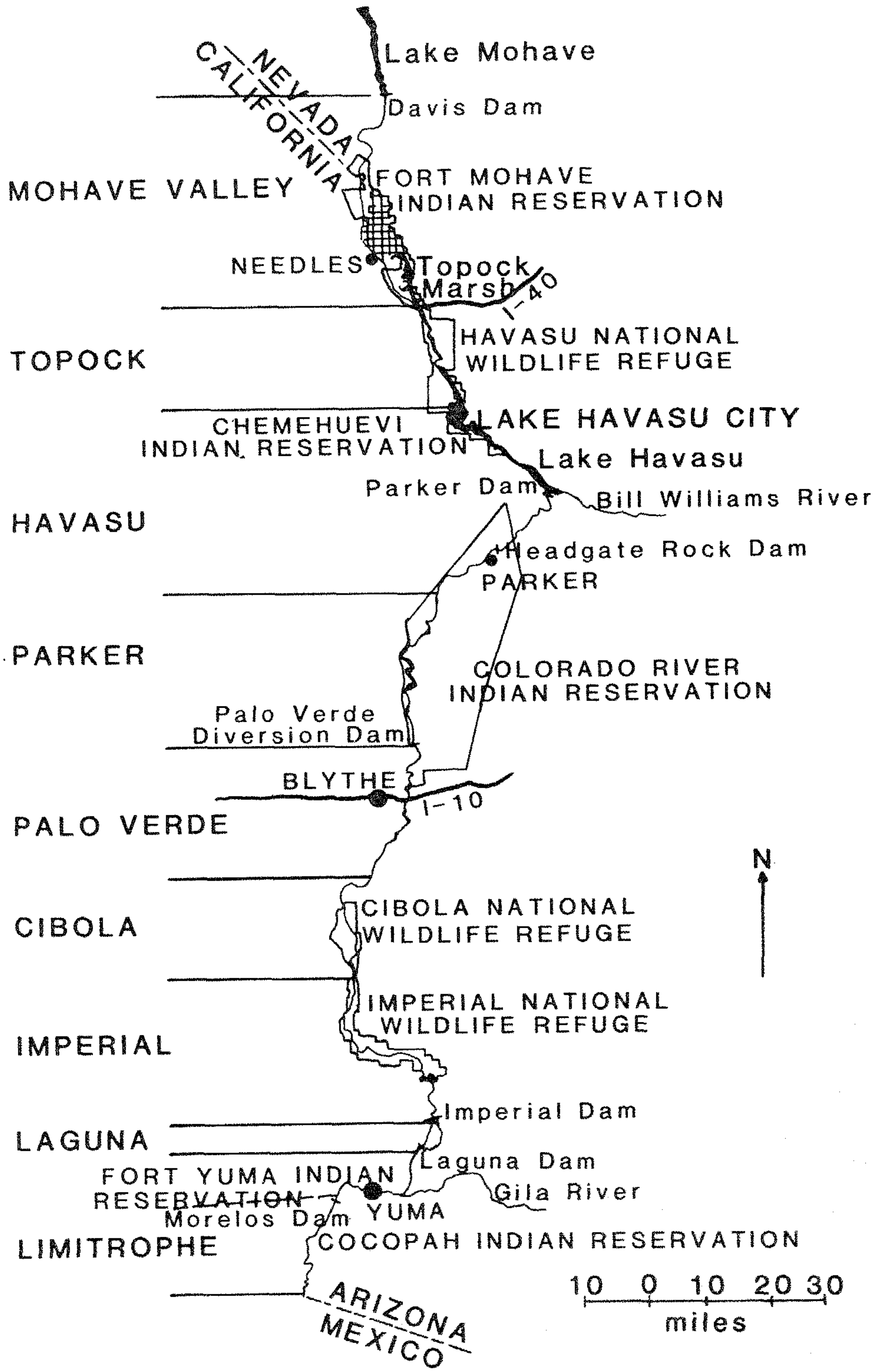

Figure 1. Map of the lower Colorado River. Bureau of Reclamation divisions are identified. Adapted from Brown (1985).

Figure 2. Modern or dredged Colorado River channel flowing through the broad alluvial valley near Parker, AZ. Almost all native vegetation beyond the river levees has been removed and replaced with agricultural crops. Vegetation within the levees is composed primarily of exotic saltcedar (Tamarix chinensis [T. pentandra]). Photo by R.D. Ohmart.

Figure 3. Parker Dam, completed in 1938, was the second major obstruction to the flow of the lower Colorado River. This dam, along with Hoover Dam completed in 1935, dramatically changed the flooding patterns of the lower Colorado River. Photo by R.D. Ohmart.

expanses of alluvial soil (Sykes 1937). The other was the river's enormous fluctuation in water levels, with an annual period of flooding between 15 May and 1 July. Peak flows were determined largely by the size of the annual snowpack in the Rocky Mountains, far to the north, and how rapidly it melted. South of Davis Dam the only tributaries of the lower Colorado River are the Bill Williams and Gila Rivers, both entering from the east and together draining much of the higher portions of Arizona and southwestern New Mexico.

The historic channel of the lower Colorado River constantly shifted except where it cut through bedrock. Within broad alluvial valleys the river meandered in a predictable fashion, constantly eroding the bank along the outside of each meander arc and depositing new soils enriched with organic material on the inside bank (Figure 4). The high sediment transport combined with variation in the postflood stages from year to year created a series of terraced "bottoms," the first bottom (lowermost terrace) being replenished and sometimes leveled annually by inundation. The second and higher terraces were inundated only intermittently, allowing a slower cycle of building and destruction and, consequently, a more stable bank formation.

Today, these alluvial valleys are marked by human settlements and agriculture (Figure 1). The northernmost valley extends from just below Davis Dam to the head of Topock Gorge and supports the towns of Bullhead City and Needles, CA. The next valley south is the Chemehuevi, which once supported a thriving population of Native Americans but now lies completely under Lake Havasu. At Parker, AZ, the valley opens again on the Arizona side and stretches south to Ehrenberg, AZ, and Blythe, CA, where the floodplain shifts to the California side of the river and extends to the town of Palo Verde. The Palo Verde Valley was formerly named the "Great Valley of the Colorado" and was among the first to be settled and farmed. The only other broad valley is in the Yuma area, from the vicinity

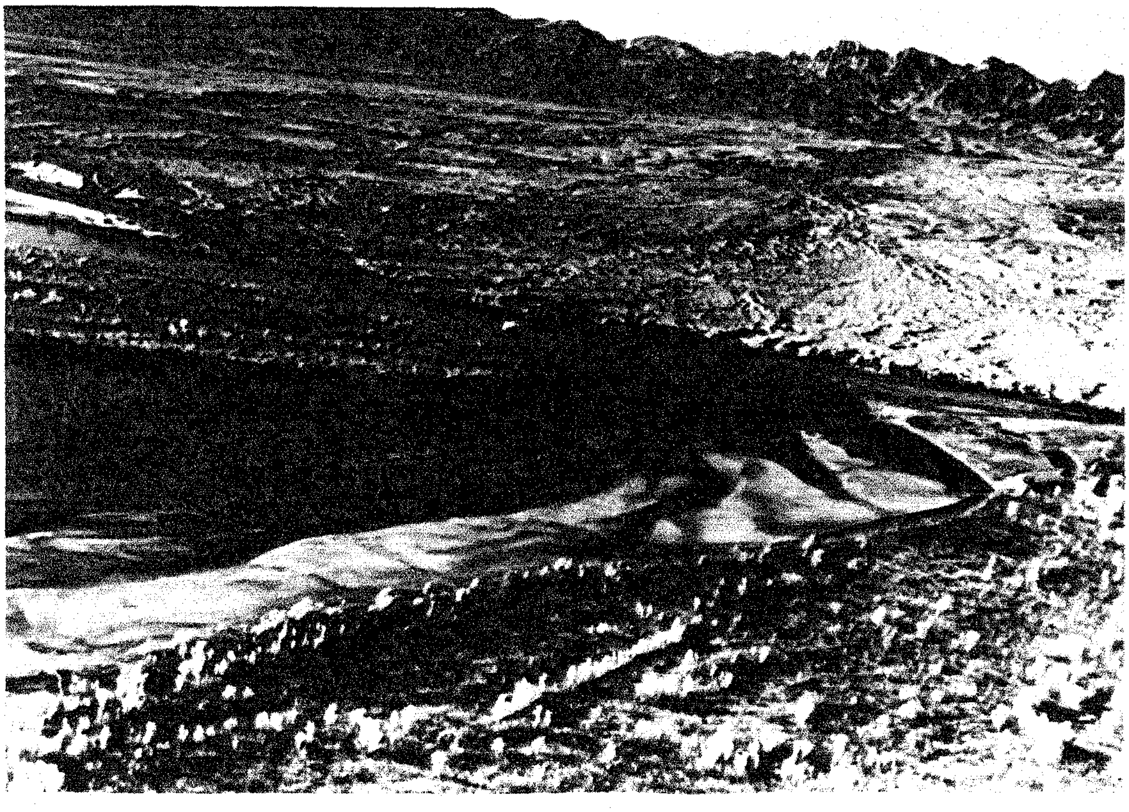

Figure 4. Lower Colorado River flowing through the valley near Parker, AZ, circa 1940. Sediment is being deposited in the outer arc providing for seedbeds supporting native riparian plants and, later, saltcedar. Photo from the files of R.D. Ohmart.

of the Gila River confluence, south into Mexico.

Bedrock portions of the river, with their relatively straight and fixed channels, are equally well-marked today, for these are the sites of dams. The valley today is still a progression of wide alluvial flood-plains alternating with narrower stretches bordered by desert hills. However, this progression is now punctuated by a series of large, shallow reservoirs (Lake Mohave, Lake Havasu, and Imperial Reservoir) (Figures 5A,B). Their fluctuating water levels inhibit the formation of a stable vegetated shoreline.

1.2 CLIMATE

Besides the topographic features of the land and the meandering river channel, an important physical feature of the lower Colorado region is its climate. By the time the river reaches Davis Dam, it has dropped to an elevation of 213 m (700 ft) and flows through one of the hottest desert regions in the world. This desert is usually referred to as the Colorado subregion of the Sonoran Desert, but in reality it is a transition between two larger deserts, the Sonoran to the east and the Mohave to the west and north. This area is hot and dry for much of the year with

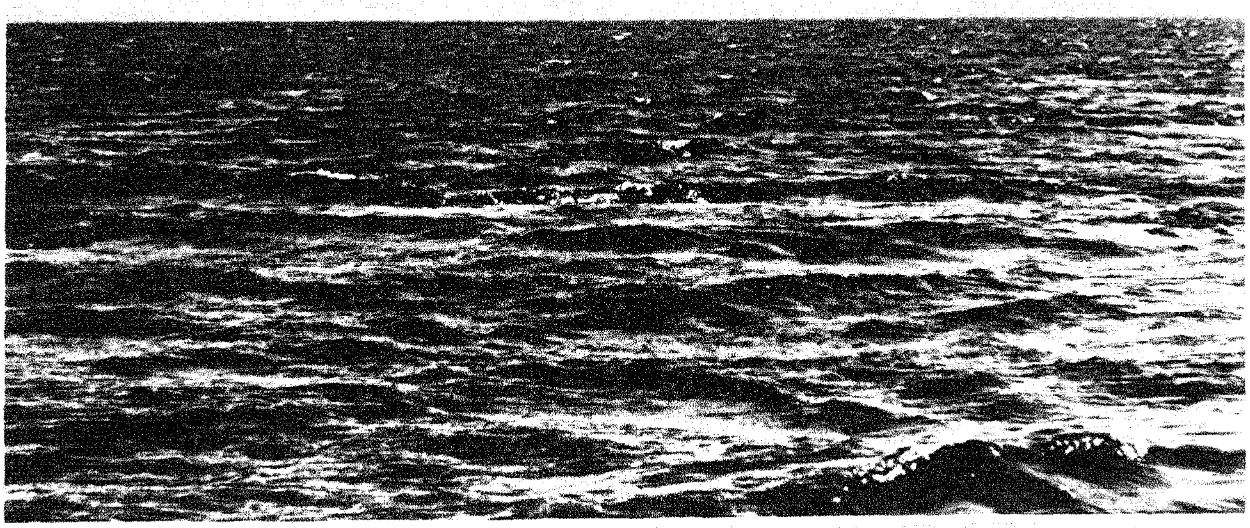

Figure 5A. Lake Havasu, created by the completion of Parker Dam in 1938.

Figure 5B. The same area before Parker Dam. Much riparian habitat and several Chemeheuvi Indian villages existed in areas now under Lake Havasu. Photos from the files of R.D. Ohmart.

summer temperatures exceeding 32 °C (90 °F) for an average of 177 days each year, and winter temperatures rarely (average of 14 days each year) below freezing (Table 1). Precipitation is low, averaging 5-10 cm (2-4 inches) per year. A short mid- and late-summer "monsoon" season, with moisture primarily from Mexico, contributes about one-third of the precipitation. During the rest of the year, brief and irregular storms, mostly originating from the northwest, make up the remainder of the precipitation. Very infrequently, a large amount of rain will fall in a short period of time. This results in huge flashfloods with standing water remaining in some areas for several months. Relative humidity is low (usually 25% or less) resulting in higher temperatures and low rainfall. The combined effects of temperatures over 38 °C (100 °F) and high relative humidity (30%+) during the late summer "monsoon" results in an extremely uncomfortable climate with little relief from precipitation.

This extreme desert climate makes the lower Colorado River very important to the region's overall biotic diversity. Its verdant floodplain valleys sharply contrast with the surrounding deserts. However, plant and animal life within the floodplain must survive both extreme heat and periodic flooding.

Table 1. Climatic trends at four locations along the lower Colorado River. Summer data are for June 1 through August 30 and winter data are for December 1 to February 28. Temperatures are °C. Data from Sellers and Hill (1974), Arizona Climate 1931-1972.

		Summer		Winter		Record extreme[a]		Precipitation				Relative humidity			
								Total cm		Days >0.25 cm		May-Sep		Oct-Apr	
Station	Elev. (m)	Avg. high	Avg. low	Avg. high	Avg. low	High	Low	May-Sep	Oct-Apr	May-Sep	Oct-Apr	0600	1800	0600	1800
Davis Dam	200	41	24	18	6	49	-6	3.10	7.54	3	10	24	15	37	26
Parker	130	41	24	21	4	51	-10	2.95	6.76	4	9	25	18	36	25
Ehrenberg	98	41	23	21	4	50	-8	3.23	5.74	4	8	34	16	39	22
Yuma Valley	37	40	21	21	3	48	-10	1.93	4.60	3	8	56	22	52	28

[a]Total days >32 °C: Davis Dam - 165; Parker - 184; Ehrenberg - 180; Yuma Valley - 180. Total days <0 °C: Davis Dam - 5; Parker - 19; Ehrenberg - 14; Yuma Valley - 18.

1.3 RIPARIAN VEGETATION OF THE FLOODPLAIN

Throughout the desert Southwest, a few plants are uniquely adapted to the floodplains of seasonally fluctuating streams. These riparian plants exist where their roots are in the capillary fringe of the water table. They may extend only as far from the channel as the stream exerts its influence through a water table. This strip of vegetation is often used to define the floodplain of a river, and creates a marked contrast as a ribbon of green bisecting the desert uplands (Figure 6).

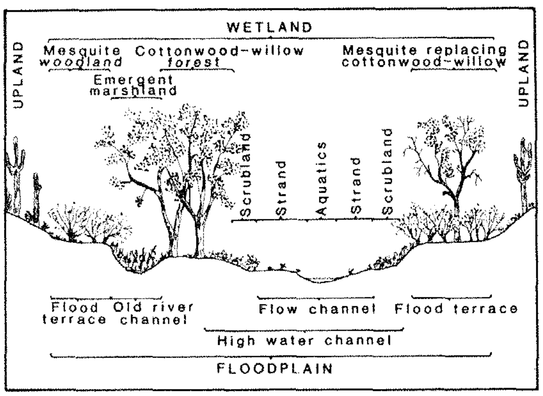

Figure 6. Semidiagrammatic representation of riparian communities in warm temperate to subtropical habitats of the American Southwest. Adapted from Minckley and Brown (1982).

The natural vegetation associations along the lower Colorado River were well described by Grinnell (1914). Belts of riparian vegetation stretched for many kilometers and filled the broad alluvial valleys. The dominant riparian forest species were cottonwood (Populus fremontii) and black or Goodding willow (Salix gooddingii). These occurred primarily on the "first bottom" and braided channels, in association with the understory shrub seepwillow (Baccharis salicifolia [B. glutinosa]) and occasionally other willows (e.g., coyote willow, Salix exigua) and emergent species (e.g., cattail, [Typha spp.] and bulrush [Scirpus spp.]) (Figure 7). As an adaptation to a frequently flooded environment, these plants were fast-growing and relatively short-lived. In fact, their existence was ultimately dependent on the cycle of annual floods that created new silt beds for seed germination. However, these and other native plants cannot tolerate prolonged inundation. Where such long-term flooding persisted, such as in oxbow lakes, emergent marsh vegetation became established (Figure 8). This marsh vegetation consisted of cattails, bulrushes or tules, and in the southern portions of the valley, cane (Phragmites australis [P. communis]).

Along the drier sites adjacent to the willow and cottonwood stands a shrub, arrowweed (Tessaria sericea [Pluchea sericea]), often formed dense monotypic belts or small strands in some areas (Figure 9). Where the floodplain of the first bottom escaped inundation for a number of years, the rare screwbean mesquite (Prosopis pubescens) grew in association with willows (Figure 10).

A very different type of riparian vegetation occurred on the second bottoms than that which existed adjacent to the river. The dominant tree in the second bottom was honey mesquite (Prosopis glandulosa [P. juliflora]) (Figure 11). This tree formed relatively sparse monotypic woodlands. The long roots of the mesquite must find permanently moist soils to ensure survival, yet the tree itself apparently cannot tolerate inundations of even a few weeks. In addition to honey mesquite, several

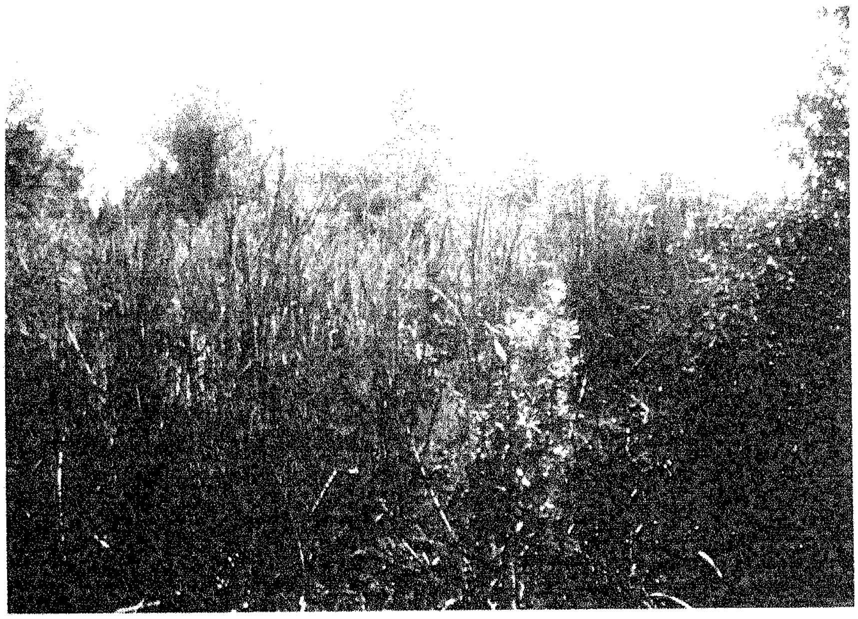

Figure 7. Close-up of recently regenerated stand of Fremont cottonwood, Goodding willow, saltcedar, cattail, and seepwillow on the Bill Williams River near Lake Havasu. Photo by D.E. Busch.

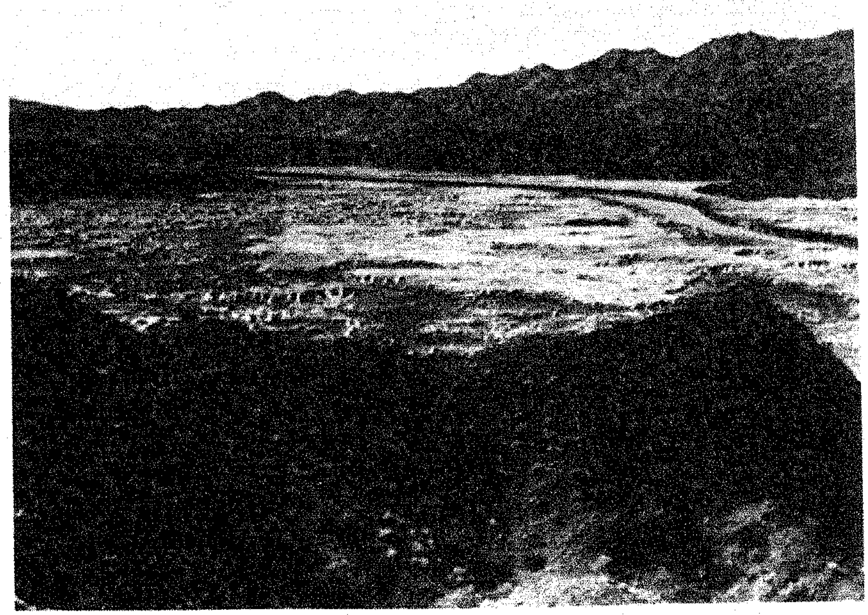

Figure 8. Cattail-dominated marsh at the Bill Williams Delta with Lake Havasu. Very high densities of Yuma clapper rail (Rallus longirostris yumanensis) are found here. Photo by D. Krueper.

Figure 9. Arrowweed habitat near Ehrenberg, AZ. Photo by W.C. Hunter.

Figure 10. Screwbean mesquite/saltcedar habitat near Water Wheel Camp, CA. This tall stand of screwbean mesquite includes scattered cottonwoods and willows. Photo by W.C. Hunter.

Figure 11. Honey mesquite habitat, without a well-developed shrub layer, near Yuma, AZ. Photo by R.E. Tollefson.

shrubs grew locally in dense clumps on the second terrace. Salt bush (Atriplex polycarpa, A. canescens) was the most conspicuous. Inkweed or pickleweed (Suaeda torreyana) preferred denser saline or alkaline soils. These shrubs formed mats between the mesquite woods and lined the bases of mesas. An additional shrub, quail bush (Atriplex lentiformis), occurred locally as a narrow belt where the first and second bottoms abutted (Figure 12).

As a whole, the riparian vegetation of the floodplain was a north-south line of greenery in the vast Colorado Desert, and was the only forest-like vegetation for hundreds of kilometers. Each of the component elements of this belt was adapted to the seemingly hostile, yet relatively predictable, local environment in which it occurred. Today's natural plant associations bear little resemblance to what Grinnell described in 1914. The cycle of annual flooding has ceased, the effect of terracing is barely apparent, and the most productive land has either been inundated by reservoirs or developed for agriculture. Although rapidly disappearing, every plant community element persists somewhere along the river today, mostly as remnants, but sometimes as quite large "islands" of vegetation. The essential character of the existing riparian vegetation has been significantly altered by the introduction of saltcedar (Tamarix chinensis [T. pentandra]) (Figure 13). This plant dominates under conditions that characterize the modern valley--frequent fire, prolonged and unpredictable inundation, and high salinity. Concomitant with the fragmentation and

Figure 12. Quail bush, salt bush, seepwillow, and inkweed dominating habitat bordering a stand of honey mesquite. Photo by J. Jackson.

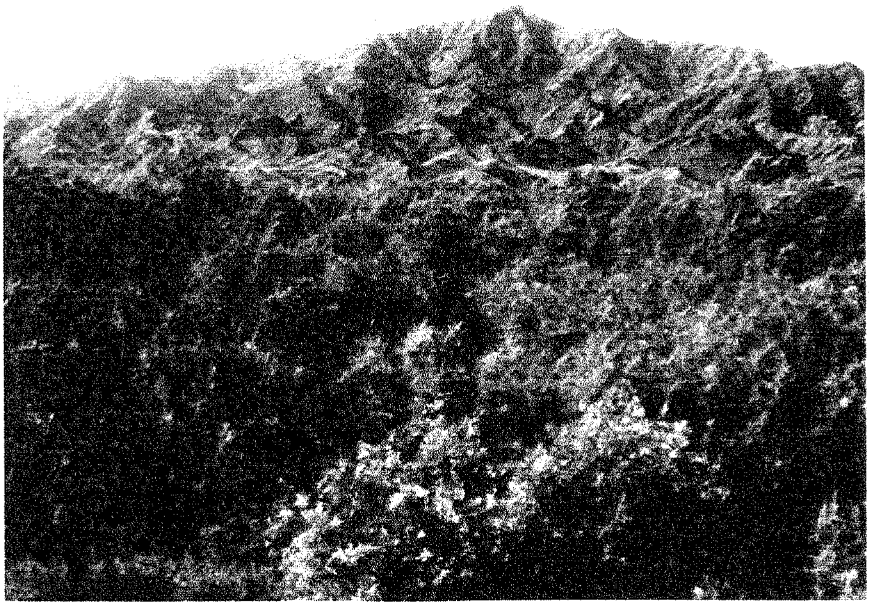

Figure 13. Saltcedar habitat near Yuma, AZ. Photo by W.C. Hunter.

alteration of riparian habitats, the native animal life has changed accordingly. However, the ultimate dependency of the wildlife and vegetation on the lower Colorado River remains unchanged.

CHAPTER 2. HISTORY OF THE LOWER COLORADO RIVER

2.1 GENERAL HISTORY OF HUMAN USE

The lower Colorado River has a long history of human use, from Native Americans, Spaniards, and Anglo-American fur trappers to modern-day Native Americans, Hispanics, and Anglos. Human dependence on and greed for water has brought about many conflicts with the natural system of the lower Colorado River. As refinement of river management increased so did modification of natural aquatic and terrestrial habitats.

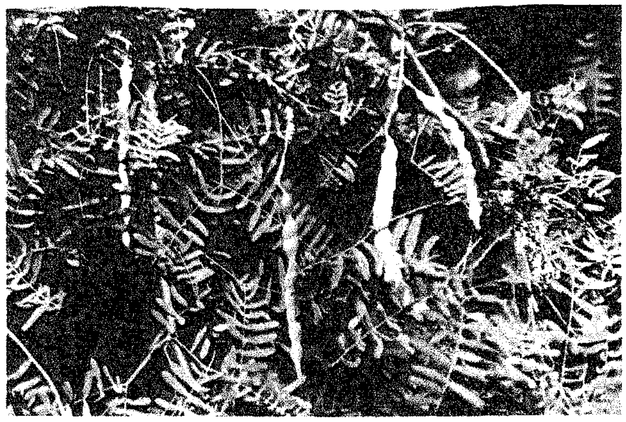

Figure 14. Honey mesquite pods which, when ripe, are important food sources for Native Americans and wildlife. Photo by R.D. Ohmart.

Our information on Native American use of the fertile lower Colorado River Valley comes primarily from the diaries of Spanish explorers. These earliest written records, combined with studies by anthropologists and bioethnologists, provide insight into the cultures and habits of these riverine people (including Mohave, Cocopah, Chemehuevi, Quechen, and Hakhidhoma; Forde 1931; Castetter and Bell 1951; Forbes 1965; Crowe and Brinkeroff 1976; Kelly 1977). These people were dependent on the annual flooding of the lower Colorado River to provide irrigation and new fertile soils. Receding summer floods each year left a wet, rich deposit of soil and organic material in which crops were planted. Honey mesquite pods were also important food sources as they contain carbohydrate- and protein-rich beans (Figure 14). If annual floods were not productive and if mesquite trees did not produce a heavy crop of beans, the indigenous people exerted greater pressure on native vegetation and wildlife by using fires to drive out food resources such as rabbits and rodents.

The Spaniards were primarily transitory explorers seeking glory and gold, along with dispersing the word of God (Bolton 1936). Priests, such as Father Eusebio Kino, entered the Colorado River Valley during the late 1600's and early 1700's, and brought herds of cattle, sheep, horses, mules, and burros. Although the Spaniards persisted for many years along the lower Colorado River, they did little to modify the lifestyle of the indigenous people. Since cattle and horses relish mesquite pods, they undoubtedly competed with the Indians for this vital resource. Conflicts between the Spanish and Indians peaked in 1781, when the Indians attacked and burned the crude missions along the river near Yuma and killed most of the resident Spaniards (Crowe and Brinkeroff 1976).

The first Anglo-Americans to reach the lower Colorado River were the fur trappers, who illegally used the river after the territory was added to Mexico in 1823. The Mexican-American War resulted in the acquisition of the lower Colorado River region by the United States Government in 1848. The Gadsden Purchase, in 1852-1854, added to the United States the territory south of the Gila River and completed the present-day international boundary with Mexico.

The next 20 years brought various members of the U.S. "Army of the West" to visit and describe the Colorado River. Several of these explorers greatly contributed to our historical knowledge of both plant and animal life, including Bartlett (1854), Emory (1848; Calvin 1951), Whipple (1856; Foreman 1941), and Ives (1861). People were drawn to the river with the discovery of placer gold in 1862. The resultant increase in steamboat traffic placed great demands on cottonwood and willow trees for fuel. Steamboat use flourished until about 1890, after which the demand for wood decreased. By this time, almost all mature cottonwoods along the lower Colorado River had been eliminated, but large-scale natural regeneration of these groves continued after each annual flood.

John Wesley Powell was the first Anglo-American to describe both the natural beauty and potential for development of the Colorado River basin to the American public. Powell's role in history is quite ironic in that he was both a forerunner for the environmental movement as well as for the forces for water development. Powell's expedition through the Grand Canyon in 1869, along with his other explorations in the West, made him uniquely qualified to set policy for the future development of the region. He understood the natural limits to development and proceeded with a conservative plan to methodically determine reservoir sites based on the system's capacity. Unfortunately, Powell's approach came at odds with the Western political establishment that wanted development based on projected needs, which far outdistanced projected supply. Powell resigned as Director of the U.S. Geological Survey and his duties for directing water development were housed soon afterwards in the new Reclamation Service, which was more susceptible to influence from Western politicians (Stegner 1953; Fradkin 1981; Reisner 1986).

By the early 1900's, agricultural activities were booming along the lower Colorado River and in Imperial Valley, CA. However, annual flooding events, especially the disastrous floods of 1905 and 1907 that filled the Salton Sea, devastated farming efforts. The Reclamation Act was passed by Congress in 1902. The 1905 floods further generated public pressure on the Federal Government to control the river for human use. Water users wanted the Reclamation Service (presently the U.S. Bureau of Reclamation) to assume responsibility for developing the river for power generation, water storage, and flood control. All of these needs could be met by a single solution: damming the Colorado River.

Laguna Dam, constructed in 1907, was the first water-management structure. When another large flood occurred in 1922, Colorado River users and their representatives pressured Washington decisionmakers into authorizing Hoover Dam. When Hoover Dam was completed in 1935, the stage was set for other river management activities. A series of lesser dams followed, with

Parker and Imperial Dams operational by 1938 and Davis Dam by 1951. River management activities following construction of these dams began to control the once wild and unpredictable flows of the lower Colorado River. These structures permanently changed the character of the lower Colorado River by ending the cycle of annual flooding that had shaped the valley over geological time.

With floods controlled and irrigation water readily available, large stands of natural habitat in the floodplain areas of the lower Colorado River were rapidly converted to agricultural uses (Figure 15). Wide portions of the floodplain near Yuma, Blythe, Parker, and Needles were cleared during the 1940's and 1950's. During this period the Bureau of Reclamation designed plans for vegetation removal to reduce evaporated water losses, but private entities removed vegetation for agricultural development so quickly and extensively that Federal designs were never implemented. The only large tracts of natural terrestrial vegetation remaining on the lower Colorado River are now on the five Indian Reservations and the three National Wildlife Refuges (Figure 1).

Native American communities soon followed the lead of Anglo-Americans in bowing to economic incentives by developing their land for agriculture during the 1960's and 1970's (Figure 16). Much of the Mohave Valley was devoid of native vegetation by 1980,

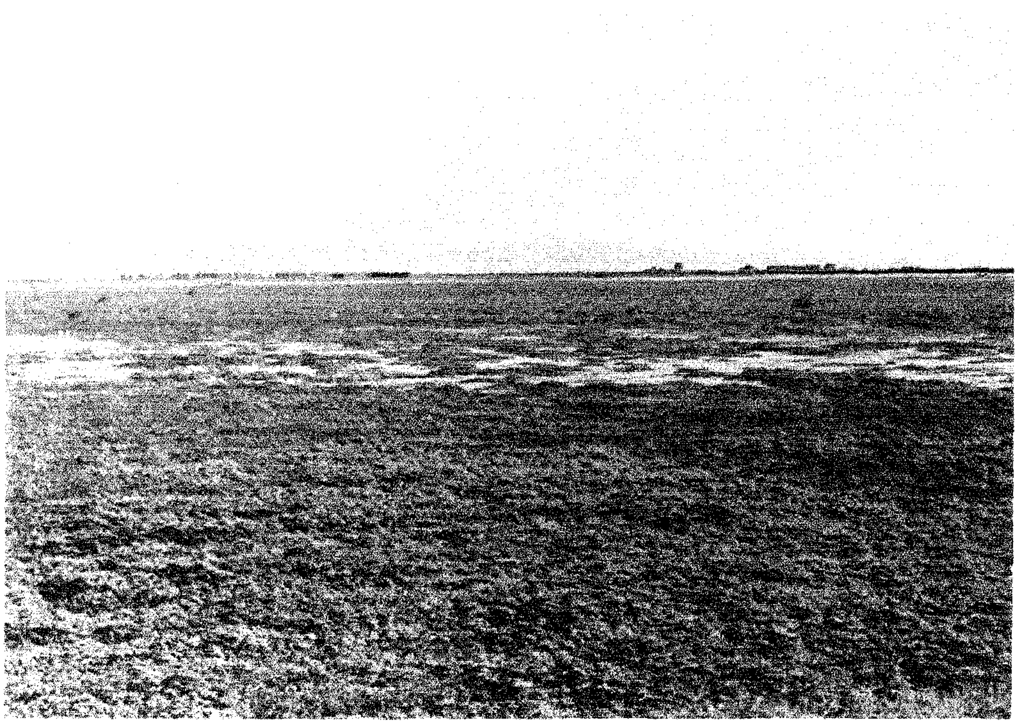

Figure 15. Alfalfa fields near Parker, AZ. Before conversion to agriculture, honey mesquite was the dominant vegetation throughout the second terrace in this valley, extending to the base of the distant mountains. Photo by W.C. Hunter.

Figure 16. Honey mesquite habitat being cleared for agriculture. Piles are burned and new saltcedar and arrowweed growth are rebulldozed. The land is then leveled and planted. Photo by D. Krueper.

and vast tracts between the towns of Parker and Ehrenberg continued to be cleared, although recent declines in farm crop prices have slowed the process. Total agriculture production on the lower Colorado River was about 120,000 ha (300,000 acres) by 1986. Most of the production is in alfalfa, cotton, and winter wheat, three crops that require vast amounts of irrigation water.

In order to more fully manage the Colorado River, engineers began to fine-tune control of the river in the 1950's through riprapping (i.e., to armor banks with large rocks) to stabilize banks, thereby minimizing channel shifts and reducing sediment transport. In areas where the channel was highly braided or contained numerous oxbows, it was deepened by dredging or a new channel was cut. In many places, old oxbow lakes or marshes lateral to these channels rapidly drained because the water table was lowered as new channels were cut or existing ones deepened. Finally, many canals were lined with concrete to reduce seepage losses (Figure 17).

In addition to agricultural development, the lure of mild year-round temperatures and an abundance of water for recreation has caused an increase in urbanization in many parts of the valley. Numerous trailer parks and various resorts now accommodate an annual migration of winter vacationers from northern states, as well as a growing number of year-round residents (Figure 18). Development of these communities has resulted in the clearing of additional riparian vegetation

Figure 17. All American Canal originating at Imperial Dam delivers water to the Imperial and Coachella Valleys, CA. Photo by R.E. Tollefson.

Figure 18. A-ha-Quin Trailer Park north of Blythe, CA. Note some mature cottonwoods remaining in the background providing some habitat for native bird species. Photo by W.C. Hunter.

and filling of emergent wetlands in areas where agriculture generally was not present.

The present-day lower Colorado River Valley supports about 200,000 people, mostly in the cities of Yuma, Blythe, Parker, Lake Havasu City, Needles, and Bullhead City. Numerous other small communities are dispersed throughout the agricultural valleys, and the riverbank is lined with trailer resorts wherever these areas are accessible by road. For the present, the lower Colorado River has been tamed and molded; what was once a formidable barrier to human settlement now supports a thriving economy based on large-scale corporate agriculture and tourism.

2.2 FLORAL CHANGES

Written accounts of explorers and missionaries in the 1600's to the mid-1800's leave the reader with a vision of cottonwood and willow forests lining the banks of the lower Colorado River, except where bedrock formed the channel. The ever-meandering river would cut away one bank and deposit new fertile soils on the opposite shore, thus providing a new seedbed for riparian trees. Oxbow lakes were frequently formed during flood-stage flows or through natural channel cutting by the river.

Slow-growing honey mesquite grew in the broad alluvial floodplains of the valley on the second and higher floodplain terraces. The hot and dry soils and seldom-flooded second terrace did not affect the status of honey mesquite, as its 15-m (50-ft) root could reach into a deep water table. More important to honey mesquite was the continuing process of second terrace formation as the river cut lower into the floodplain.

Spring floodwater, containing silt and organic debris, spread new soil and nutrients over the floodplain. Trees, shrubs, and vines were abundant, making travel along the river or attempts to cross it difficult. Wild grape (Vitis spp.), wolfberry (Lycium spp.), mistletoe (Phoradendron californicum), and other berry-producing plants provided a rich and varied food resource for wildlife.

Raging floods uprooted thousands of hectares of forest vegetation in some years, but the flood-adapted riparian plants quickly reinvaded denuded areas. The river was dynamic, as was the vegetation that grew on its floodplain.

There is some controversy concerning the original number, extent, and duration of backwaters along the lower Colorado River north of the border with Mexico. Ohmart et al. (1975) studied the dynamics of emergent wetland formation along the river, reviewing historical records and evaluating factors responsible for early marsh development. Early diaries (unpubl.) contain accounts of persons wandering for several days in wet areas that were choked with tules and other thick undergrowth, especially near Yuma. These accounts initially create the impression that these marshes were quite extensive and persistent.

However, study of the better-known and better-named backwaters in the historical record suggests that most backwaters were of small size, and their total lifespan was rarely more than 70 years and usually less (Ohmart et al. 1975). Another convincing perspective is offered by the noted biologist, Dr. Joseph Grinnell (1914), who led an expedition that floated the river from Needles to Yuma in 1910. Grinnell and his party, from the Museum of Vertebrate Zoology at the University of California-Berkeley, were on the river for three months collecting biological data. They compiled extensive field notes, collected plant and animal specimens, and studied the river as an ecological resource. Grinnell's party was on the river prior to the construction of any major dams (Laguna Dam was built in 1909 but silted in within six months). Of backwaters, Grinnell (1914:72-73) stated:

> The river's habit of overflow would be expected to result in rather extensive tracts of palustrine flora. As a matter of fact, however, marshes were few and of small size. This was probably due to the rapid rate of evaporation of overflow water so that favoring conditions did not last long, and also to the rapid silting-in of such water basins as ox-bow or cut-offs. As a result there were either almost lifeless alkali depressions, or lagoons practically identical in biotic features with the main river. But in a few places there were well-defined palustrine tracts kept wet throughout the year, chiefly by seepage. They were marked by growths of tules, sedge [*Carex* spp.], and salt-grass [*Distichlis* spp.], sometimes the latter alone, and were usually surrounded by the arrowweed or willow association.

Prior to the construction of dams, the Colorado River was unpredictable in amount of flooding and instream flow. This unpredictability contributed to the development of ephemeral backwater wetlands. Grinnell (1914) gave the extremes of river flow as 113 to 2,832 m^3/sec (4,000 to 100,000 ft^3/sec), with the lowest flows occurring in midwinter and the highest in June. This high annual fluctuation in flow, combined with a constantly meandering channel and an arid desert climate, explained the short life expectancies of most backwaters. In addition, big floods carried heavy sediment loads that settled out as the floodwaters receded, expediting the filling and drying of many marshes. Finally, seepage or subterranean water flow into the backwaters came primarily from washes that entered the valley from adjacent desert mountain ranges. In a climate where annual rainfall averages about 5 cm (2 inches), these flows are too small to maintain permanent marshes.

Although marshy backwaters and oxbow lakes were apparently limited and of short duration, they were important features to aquatic life along the lower Colorado River. They provided production of aquatic and semiaquatic vegetation that supplied organic matter in the form of detritus (Minckley 1979). The existence of a well-developed terrestrial riparian community along the river certainly gave rise to substantial amounts of organic materials, especially during flood events. Debris from riparian vegetation is known to play a major role in nutrient flow in low desert rivers through slow decomposition of the organic material (Rinne 1973, 1976; Bruns 1977).

During the brief heyday of steamboat traffic in the mid-1800's, virtually any tree large enough or close enough to the river was burned for fuel. However, the natural resiliency of riparian vegetation ensured that the cottonwood and willow trees would regenerate. The raging floods of 1905 and 1907, however, slowed this normal rapid regeneration. By 1910, Grinnell found the willow-cottonwood association thriving in the river bottomlands once again, without mention of a conspicuous lasting impact either by the fuel-wood cutters or the prolonged floods.

Grinnell (1914:61) did, however, describe in detail the observable effects of the first dam, Laguna, on the lower Colorado River when he wrote:

> The water level had been raised conspicuously for at least ten miles, and we saw evidence of deepening of the first-bottom deposits and slowing of current for fully thirty miles, above the dam. The cottonwoods of the first-bottom had all been killed, evidently by the raising of the general surface around their trunks; and the mesquites and other vegetation of the second-bottom had all been drowned out, there thus being no trace of second-bottom conditions except for dead stalks. These were replaced by vast mudflats growing up to arrowweed. All of this change, of course, involved the birds and mammals of the area affected, in addition to the plant life.

What Grinnell witnessed on a small scale, he could not have guessed was to be an accurate prelude to the changes in the coming decades.

Two major events and their consequences have dictated the demise and, possibly, the eventual disappearance of the cottonwood and willow forests along the lower Colorado River (Figures 19A,B,C,D). First, by 1936 Hoover Dam essentially stopped all threats of floods, except when heavy runoff from local rains brought floods from larger tributaries, such as the Bill Williams River. Farming of the rich alluvial soils increased with the cessation of flood threats. Without floods, new rich alluvial seedbeds were no longer formed and the life-history cycle of the cottonwoods and willows was irreversibly changed. In addition, lakes behind Hoover Dam, and other dams that followed, inundated thousands of hectares of riparian habitat. Of these rapid changes in the lower Colorado River Valley after Hoover Dam, Phillips et al. (1964:xv) commented:

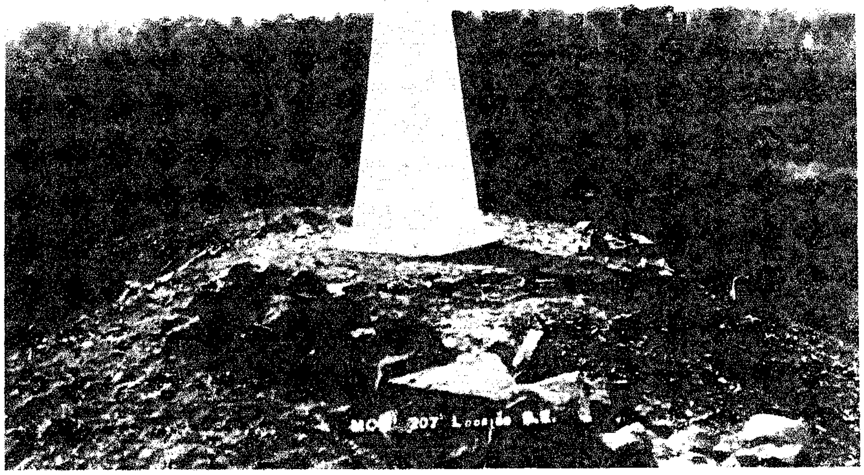

Figure 19A. View of mature cottonwood-willow habitat in 1894, from the U.S.-Mexico International Boundary, Monument 207, facing southeast. Photo from the files of R.D. Ohmart.

Figure 19B. Same area as in (A) in 1976. Note the absence of contiguous broadleaf forest. Photo by W. Deason.

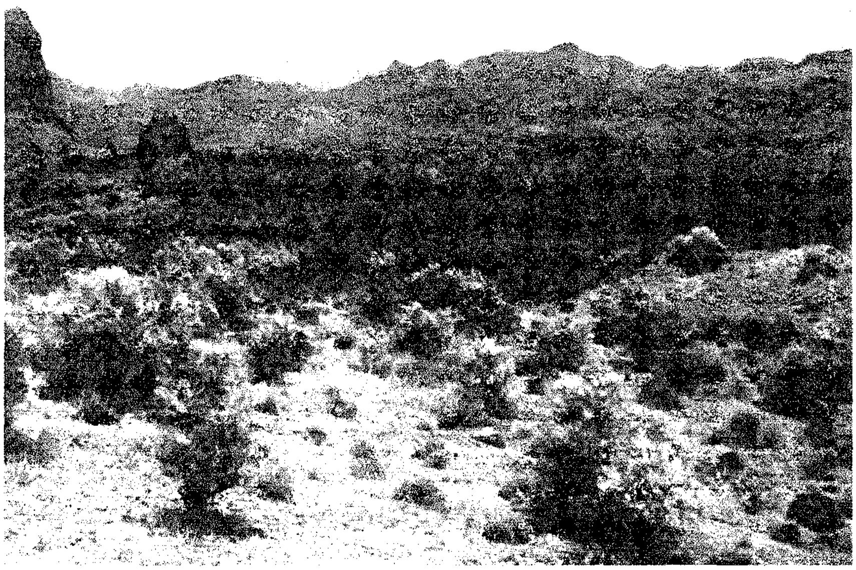

Figure 19C. Mature cottonwood-willow habitat in 1979 near the Bill Williams Delta with Lake Havasu, AZ. This was the last large stand (approx. 120 ha [300 acres]), dominated by relatively mature Fremont cottonwood for the entire lower Colorado River region. Photo by A. Laurenzi.

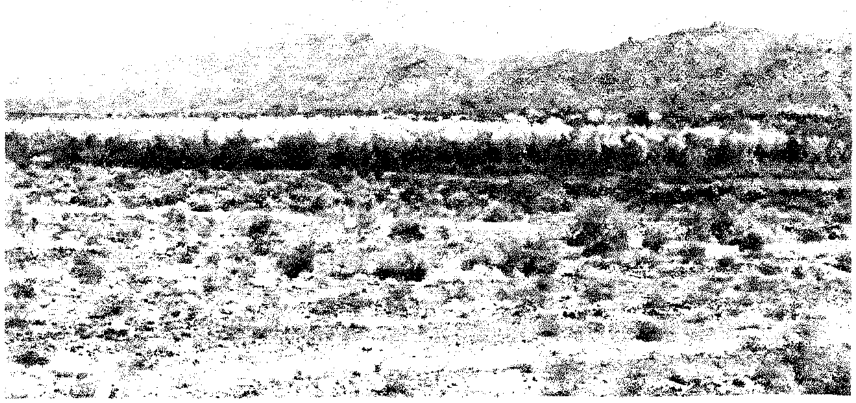

Figure 19D. Same stand as in (C) after 2 years of flooding (1981). Note that almost all cottonwoods have died leaving an upper midstory dominated by Goodding willow.

> ...The river became a steady, clear-flowing stream that no longer annually overflowed its banks to create lagoons and silt flats. The building of this and other dams produced large lakes of clear, open water that drowned much excellent bird habitat. Most of the surviving river-bottom habitat has been cleared, leveled, and converted to farmlands....Perhaps nowhere else in Arizona have the changes been more dramatic.

The second major event took place sometime around 1920, when an exotic species of tree, saltcedar, spread into the lower Colorado River Valley from the Gila River. Saltcedar found optimal ecological conditions for its spread and eventual dominance. In 1894, Mearns (1907) estimated that there were about 160,000 to 180,000 ha (400,000 to 450,000 acres) of alluvial bottomland between Fort Mohave and Fort Yuma covered by riparian vegetation. As of 1986, total riparian vegetation was about 40,000 ha (100,000 acres) (Anderson and Ohmart 1984c; Younker and Andersen 1986), approximately one-quarter of the available bottomland estimated by Mearns. Roughly 40% of the remaining area in 1986 was covered by pure saltcedar stands, an additional 43% consisted of native plants mixed with saltcedar, and only 0.7% (307 ha [768 acres]) could be considered mature cottonwood or willow habitats.

The successful spread of saltcedar is an example of an introduced species optimally exploiting an environment disturbed by humans, to the detriment of native vegetation. Initially, saltcedar became established in areas where native vegetation had been cleared and the land left fallow (Ohmart et al. 1977). Saltcedar has a high rate of seed production with as many as 600,000 seeds per plant produced from April through October (Robinson 1965). The long period of seed production allows saltcedar to germinate well into fall, when most native trees are no longer producing viable seeds. Saltcedar has become dominant along the lower Colorado River by being salt-, fire-, and flood-adapted.

Where channelization and river-flow management have resulted in very little native plant regeneration, senescent stands of mesquite or willow are replaced by saltcedar. In addition, soil and water salinity levels have risen dramatically in association with irrigation practices and evaporation from reservoirs. Native plants, with the exception of salt bush and quail bush, exhibit a low tolerance to saline soils. In contrast, saltcedar thrives under highly saline conditions.

Saltcedar is typically deciduous and, without floods, large amounts of leaf litter accumulate. Therefore, the possibility of a stand igniting increases, especially during the dry summer months. After such fires, saltcedar and arrowweed quickly regenerate, whereas cottonwood and quail bush usually fail to return (Figure 20A). Thus, in stands of mixed vegetation saltcedar will be the first to regenerate, and through successive fires eventually displaces most native species (Figure 20B). Currently, saltcedar is the numerically dominant tree along the entire length of the lower Colorado River.

Riparian areas, especially on Indian lands, are still being cleared for agricultural and residential developments. The last of the large continuous mesquite bosques remaining on the lower Colorado River were beginning to be cleared in 1984. About 800 ha (2,000 acres) of the

Figure 20A. Five months after burning of a saltcedar-honey mesquite habitat at Cibola National Wildlife Refuge. Most mesquite died rapidly after the fire. Photo by J. Jackson.

Figure 20B. Two years after a burn with vigorous growth evident for saltcedar, but not for native trees. Photo by W.C. Hunter.

lower Colorado River mesquite land were cleared north of Ehrenberg by the end of 1984 for conversion into agricultural production. In addition, some of the most important screwbean mesquite habitats are being cleared presently for agriculture, and also for new trailer-recreational vehicle parks.

Channel straightening and armoring was completed along most of the lower Colorado River by the U.S. Bureau of Reclamation to increase the efficiency of water transport and to reduce riverbank erosion. Hydrologically, channel dredging (or deepening) lowered adjacent water tables, which effectively drained most backwaters along the lower Colorado River. Cessation of floods precluded development of new backwaters. Finally, dredge spoil was deposited in backwaters to decrease surface area and retention time of water (Minckley 1979). All these activities have decreased the amount of circulating organic material in aquatic habitats that would be available for primary productivity.

Ironically, the most recent cause of vegetational change along the lower Colorado River is the same factor that was most essential to the continuing health of the entire system, that is flooding. Before dam construction natural floods typically lasted only a few months, whereas recent high water releases from dams may last for 12 or more months. After 1935, the river had not overflowed its prescribed channel until the summer of 1983, when water releases from dams exceeded any previously recorded controlled flows. The long duration of high flows during 1983, 1984, and again in 1986 resulted in the death of most of the remaining cottonwoods along the river (Figure 21). Cottonwood and mesquite are highly intolerant of long-term flooding, whereas willows are considerably better adapted to long-term inundation. Native plant regeneration is limited by timing of the flood and by high soil salinity, both which now favor saltcedar establishment. Even though some regeneration of cottonwoods and willows has occurred many more hectares have been lost. The recent floodwaters have also covered many hectares of emergent vegetation with sediment and debris, while other marshes have been totally scoured of their vegetation. Some marshes benefit temporarily from inundation, however, because emergent plants regenerate and spread quickly on new silt beds covered by shallow water. This aggradation of material eventually allows the reestablishment of terrestrial vegetation, most of which probably will be saltcedar. Much of the submergent vegetation has yet to recover from recent flooding.

2.3 FAUNAL CHANGES

Two animal groups, fish and birds, have shown dramatic changes in association with increased river management on the lower Colorado River since the mid-1800's. Some changes also have occurred in other faunal taxa. Native fish and bird species have declined or have been extirpated, while many introduced species of fish and both introduced and native species of birds have increased.

The native fish fauna of the lower Colorado River consisted primarily of nine species, all but one of which are presently extirpated from the mainstream or are extremely rare (Minckley 1979). Three of these species were essentially marine and all but one, the striped mullet (Mugil cephalus), have been cut off from the river by Morelos Dam downstream of Yuma. Five species compose a group of big-river fish, all of which have declined to near extirpation, that disappeared from the river between the 1950's and

Figure 21. Vegetation, mostly saltcedar and honey mesquite, flooded during 1983. Mesquite died rapidly. Note debris piled in open lanes and the renewed saltcedar growth under these conditions. Photo by D. Krueper.

1960's (Figures 22A,B,C). Another species, the desert pupfish (Cyprinodon macularius), was a species of marshes and backwaters and has not been recorded from the mainstem river since the early 1900's.

The present fish fauna of the lower Colorado River is composed almost exclusively of introduced species. Of the 24 introduced species (Minckley 1979), 16 are from the Mississippi River Valley region, 4 are from the Old World, 2 are from Middle America, and 2 are anadromous (one from the Atlantic and the other from Pacific drainages). The declines in the native ichthyofauna are related to both habitat changes and interspecific interactions (including competition and predation) from introduced species and are discussed in more detail in Chapter 9.

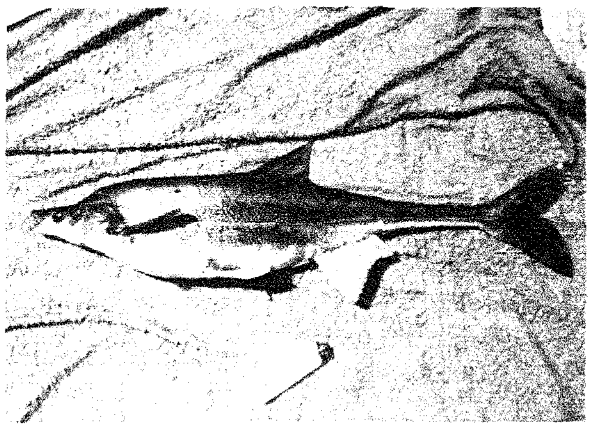

Figure 22A. Three species of Southwestern big-river fishes that were all once abundant in the lower Colorado River. Bonytail chub (Gila elegans) is now found only in very low numbers at Lake Mohave, while it is apparently extirpated throughout the rest of its historical range. Photo by W.L. Minckley.

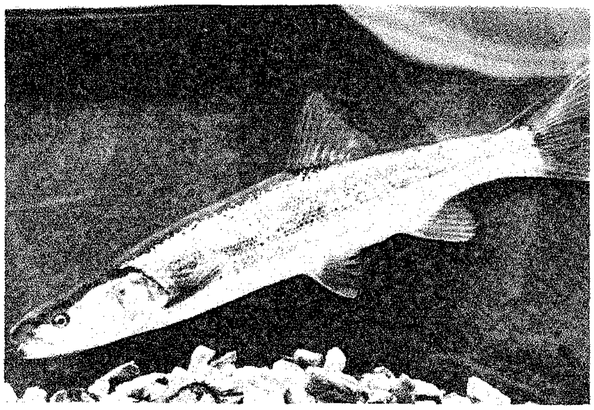

Figure 22B. Colorado squawfish (Ptychocheilus lucius) is extirpated from the Colorado River below Glen Canyon Dam. Photo by J.N. Rinne.

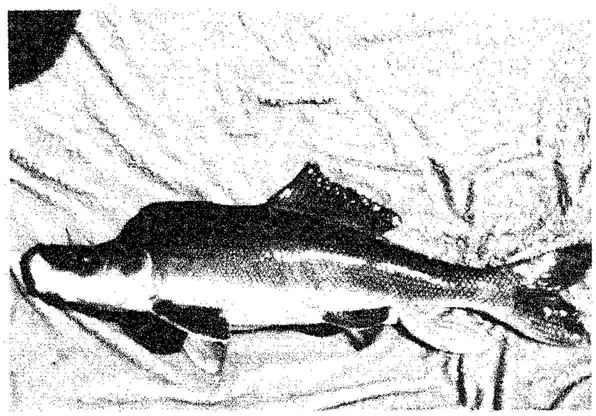

Figure 22C. Razorback sucker (Xyrauchen texanus) still can be found at Lake Mohave and a few other localities in the lower Colorado River, but natural recruitment is virtually unknown. Photo by P.C. Marsh.

Changes in the avifauna generally can be divided into three different categories: (1) species that have declined with the loss of riparian habitats, (2) species that have increased with the conversion of these lands to farm land, reservoirs, or marshes, and (3) species that have expanded their geographic ranges in recent years to include the lower Colorado River Valley. Historically, seven summer-resident insectivores were considered common or abundant (Grinnell 1914; Swarth 1914), being characteristic elements of the bottomland cottonwood-willow associations (Figure 23). All of these species have declined sharply in numbers concomitant with the loss of large stands of mature cottonwood-willow habitat. In addition, three species of cavity-nesting birds also have declined with the decrease of tall snags or elevated dead, soft wood associated with cottonwood-willow habitats.

Figure 23. Yellow-billed cuckoo (Coccyzus americanus) with katydid in a Goodding willow. The cuckoo has declined in population size dramatically since the 1970's, and is now close to extirpation along the lower Colorado River mainstem. This species is representative of a dozen deep-forest, insectivorous birds nearing extirpation in the lower Colorado River Valley. Photo by K.V. Rosenberg.

Although the increase in agricultural lands in the valley has had a negative impact on the breeding avifauna, many migratory and wintering species use these areas extensively. Some species undoubtedly visit the valley more frequently as the open habitats they prefer have become more prevalent. Some riparian species may also benefit from the agricultural-riparian edge that provides food as well as adjacent shelter and nest sites. However, other species that interfere with the nesting of riparian birds by either being predators or nest parasites have also increased (e.g., European starling [Sturnus vulgaris], brown-headed cowbird [Molothrus ater], bronzed cowbird [M. aeneus], great-tailed grackle [Quiscalus mexicanus]).

Changes have resulted in the development of open water and marsh habitats. In these situations, many waterbirds have benefited. Grinnell (1914:72-73) commented on the paucity of waterbirds in 1910:

> ...The little open water sometimes attracted a few transient ducks and mudhens, but so far as known no water bird outside of the Ardeidae remain to breed anywhere along the Colorado River.

Among the many waterbirds occupying these habitats today is the Federally endangered Yuma clapper rail (Rallus longirostris yumanensis) (Figure 24).

The almost annual occurrence of rare duck species and typical oceanic species is associated with the formation of the large lakes and deep channels not historically found along the lower Colorado River. Dispersing waterbirds from the Gulf of California are also attracted to these large bodies of water. With a decline of native riparian breeding birds there has been an increase in the establishment and expansion of primarily wintering species associated with agriculture, open water, and marsh habitats.

Figure 24. Yuma clapper rail is the only bird species on the Federal endangered species list with the center of its distribution on the lower Colorado River. Photo by R.E. Tomlinson.

The large diversity of bird species now found along the lower Colorado River is primarily a result of changes undertaken to "modernize" the river. A number of species not found in Grinnell's day are now common or increasing. However, the valley's original breeding avifauna associated with pristine riparian habitats, like the original ichthyofauna associated with pristine aquatic habitats, is in jeopardy.

CHAPTER 3. HYDROLOGIC, LIMNOLOGICAL, AND TERRESTRIAL PHYSICOCHEMICAL CHARACTERISTICS OF THE LOWER COLORADO RIVER SYSTEM

3.1 HYDROLOGY

Pre-1935

The Colorado River drains a total area of 630,000 km^2 (378,000 mi^2). The recorded range of flow through Yuma was from 0.34 to 7,083 m^3/sec (12 to 250,132 ft^3/sec) (U.S. Geological Survey 1973). Sediment loads during flood stage averaged more than 10^8 t (11.02 X 10^8 tons) per year from 1925 to 1935. During normal flows and during drought periods the river ran clear (Minckley 1979).

The average annual undepleted surface flow of the lower Colorado River was estimated to have been 1.8 X 10^{10} m^3 (14.6 million acre-ft) from 1896 to 1935 at Lee's Ferry, AZ (Lower Colorado River Comprehensive Framework Study 1971). About 1.9 X 10^{10} m^3 (15.4 million acre-ft) virgin flow was estimated to flow into Mexico. With local runoff and tributaries considered, an additional 3.9 X 10^9 m^3 (3.12 million acre-ft) would be added to undepleted water flowing into Mexico.

Groundwater distribution and availability are determined largely by the geologic setting of the area. Subsequent to major faulting that formed the mountains and valleys, several stages of erosion and sedimentation filled the valleys with materials that now form the major aquifers adjacent to the lower Colorado River. This older alluvial fill consists of gravel, sand, clay, and silt layers in varying thicknesses; locally, it may be as much as 914 m (3,000 ft) thick. In general, the deposits grade in texture from large boulders near the mountains to fine-grained silt along the axis of the valleys.

Where clay beds form a confining layer, the groundwater beneath is under artesian pressure. Groundwater in the coarse materials above the clay beds is under water-table conditions. Localized clay beds within coarse materials sometimes support widespread perched or semiperched water bodies (Lower Colorado River Comprehensive Framework Study 1971).

The present drainages, cut in the older alluvium, have been filled to various depths with unconsolidated deposits of gravel, sand, and silt. In many basins this younger alluvial fill, along the floodplain of the present stream, provides large amounts of groundwater. The amount of groundwater that can be obtained from the younger fill in any particular area depends on the depth and extent of the deposits.

Not surprisingly, the major aquifers are located in the broad alluvial fans found in the Mohave, Parker, Palo Verde, and Imperial Valleys. Depth to water table in these valleys is <61 m (<200 ft). Recoverable groundwater in storage amounts to about 9.9 X 10^{11} m^3 (803 million acre-ft) along and adjacent to the lower

Colorado River, with 6.9×10^{10} m^3 (56 million acre-ft) within the upper 30 m (100 ft) of saturated thickness.

Post-1935

Tremendous demands were projected for Colorado River water by the 1930's for agricultural development and later for residential development. These demands necessitated tremendous control over the Colorado River's water resources. The first attempts at tapping local water resources of the lower Colorado River consisted of levee construction and various structures to direct surface water for irrigation (U.S. Bureau of Reclamation 1948). When Hoover Dam was closed in 1935, the lower Colorado River bed began to degrade below it. Eroded materials were deposited near the entrance of Topock Gorge and formed Topock Marsh. Rising water levels near the towns of Needles and Bullhead City prompted extensive dredging operations and the construction of levees along the river.

Parker Dam was constructed in 1938 to entrap sediments and to provide a basin for the intake of water to southern California. Channelization, bank stabilization, and dredging were initiated downstream of Parker Dam south to the lower end of Cibola National Wildlife Refuge to lower the water table and expedite flows down the river. These operations were mostly completed by the late 1960's.

Imperial Reservoir, the third major impoundment developed in the 1930's, was built to provide a settling basin and to supply water to the Imperial Valley. Since its formation this shallow reservoir has been dredged, when required, to maintain flows and surface water for recreation. The last diversions of river water occur at Laguna Dam for the lower Gila River Valley and at Morelos Dam for Mexico.

Davis Dam, the last of the major dams on the lower Colorado River, was closed in 1954. Lake Mohave partially serves as a storage basin for water eventually destined for Mexico. Davis Dam stopped all sediment movement on the river. Although Hoover Dam allowed for the water diversions downstream, almost all water management activities are below Davis Dam. Thus, the Bureau of Reclamation defines the management boundary between lower and upper reaches of the river at Davis Dam.

About 332 km (144 mi) of the lower Colorado River's 444 km (276 mi) below Davis Dam are within levees and have been channelized or dredged. All but 11 km (7 mi) of the leveed banks have been armored with riprap. In 1987, another 11 km (7 mi) was proposed for bank modification in the Yuma Division. Additional work may soon be delineated for Parker II Division. Extensive river management work was conducted in the Mohave Valley from 1945-1960, Parker Division from 1966-1968, Palo Verde Division from 1962-1968, Cibola rechannelization (straightening the river flow) from 1964-1970, Laguna Division from 1968-1969, and in the Yuma Division from 1951-1952. Channelized sections of the lower Colorado River average about 150 m (492 ft) in capacity width. Areas not bordered by levees upstream of Imperial Dam and below Cibola National Wildlife Refuge range from 60 to 500 m (197 to 1,640 ft) wide. Depth capacity also vary with modifications, ranging to about 8 m (26 ft) in the deepest parts of unmodified reaches (such as Topock Gorge), averaging 3.5 m (11.5 ft) in channelized segments, and <3.5 m (<11.5 ft) where the river valley is broad (as in the Parker and Limitrophe Divisions). Reservoirs, primarily Havasu and Mohave, can be deep, >18 m (>59 ft), but most places are <8 m (<26 ft) deep.

Historically, along many reaches of the lower Colorado River, the channel was highly convoluted, shallow, and braided; dredging of the river has generally been to deepen and straighten the channel, which has cut off backwaters and lowered adjacent water tables. The constant tendency of the river to meander and erode banks has prompted the Bureau of Reclamation to stabilize the banks with riprap.

Water flow on the lower Colorado River is regulated by discharges from both Davis and Parker Dams, and by water delivery and diversion at the other dams along the river. Seasonal and daily cycling of water flow reflect demands on the system for power generation and irrigation. Highest demands are during the daylight hours for power generation and during summer for irrigation.

The floods of 1983, 1984, and 1986 dramatically changed the stable flow patterns established in 1935. These floods resulted in large amounts of water reaching the Delta for the first time since closure of Hoover Dam (Table 2). At present, dredging operations, reinforcing old levees, establishing new levees, armoring banks with riprap, and water salvage (vegetation removal) projects are ongoing to continue control of the river by reducing high sediment beds, improving navigation, and providing for further flood control.

The lower Colorado River, in floodstage, formerly scoured and redistributed sediment throughout the system (Table 3). Presently, boulders and gravel are prominent immediately below Davis and Parker Dams (Minckley 1979). In channelized segments (such as in the Palo Verde and Cibola Divisions) the predominant sediment is sand. Silt is predominant only in Lake Havasu.

Prior to 1935 extensive vegetation bordering the river may have helped to buffer water temperatures and trap suspended sediments during floods. The importance of the latter in preventing erosion and trapping suspended soils should not be overlooked. Riparian vegetation helps to slow water velocity, especially during high flow events. As velocities are reduced, any sediment being transported by the fast-moving water is deposited laterally out of the main flow.

Presently, the river flows mostly through areas of denuded banklines (except in the Imperial Division) and receives direct insolation. Topock Gorge is the only section where cliffs are high enough to shade the river and buffer daytime temperatures. The rest of the river is subject to rapid heating on the surface during the day balanced by evaporation into dry air, and equally rapid cooling at night by evaporation (Minckley 1979).

The extreme fluctuations in recorded flow volumes before 1935 ceased after closure of Hoover Dam. From 1935 to 1983, flows were relatively constant in upper reaches among seasons and years (Table 2, Figure 25). Flows at lower reaches were more variable among seasons, with highest rates during summer when energy and irrigation demands were greatest. Flow rates before 1983 at Davis and Parker Dams were around 283 m^3/sec (10,000 ft^3/sec), and at the International Boundary they were 142 m^3/sec (5,000 ft^3/sec) at Morelos Dam. During the floods of 1983, peak flows below Parker Dam were about 1,163 m^3/sec (40,690 ft^3/sec), and flows on the river remained very high into 1986.

Presently, virtually all Colorado River water is allocated. No planned flows have reached the Colorado River

Table 2. Monthly water flow through three stations along the lower Colorado River. Data from U.S. Department of the Interior (1987).

Calendar year	Mean 1,000 acre-ft±SD (X16.8 to ft^3/sec or X0.4757 to m^3/sec)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Hoover Dam												
1941-1949	1,192±	1,059±	1,101±	1,006±	1,124±	1,147±	1,028±	1,007±	1,041±	1,119±	1,112±	1,288±
	372	299	264	242	178	323	149	210	239	247	297	339
1950-1959	922±	803±	1,011±	1,022±	1,016±	870±	915±	902±	851±	761±	763±	805±
	273	254	253	230	225	217	160	163	212	218	211	268
1960-1969	500±	530±	821±	853±	877±	780±	847±	794±	666±	543±	486±	495±
	114	49	61	68	33	82	67	86	82	49	62	81
1970-1979	448±	542±	786±	887±	915±	764±	823±	832±	627±	514±	450±	480±
	154	112	110	75	79	75	45	85	81	76	74	69
1980	472	268	930	1,129	1,260	1,057	1,190	1,194	879	987	837	885
1981	619	536	815	1,016	857	835	864	915	663	379	388	397
1982	463	548	792	1,042	843	635	735	764	394	393	379	464
1983	1,176	365	634	1,060	1,216	1,886	2,574	2,422	2,187	2,106	1,750	1,692
1984	1,888	1,765	1,770	1,564	1,887	2,076	2,185	1,905	1,622	1,588	1,544	1,618
1985	1,752	1,582	1,402	1,330	1,436	1,665	1,735	1,684	1,218	---	---	---
Parker Dam												
1941-1949	1,157±	1,030±	1,098±	955±	1,096±	1,062±	996±	970±	984±	1,052±	1,086±	1,216±
	355	269	237	189	236	303	135	187	245	254	269	329
1950-1059	799±	676+	908±	907±	898±	911±	981±	934±	771±	652±	594±	660±
	364	277	308	232	251	187	118	149	200	218	245	351
1960-1969	323±	441±	690±	696±	666±	768±	869±	794±	585±	423±	301±	267±
	71	32	53	68	49	65	67	61	55	39	72	58

(Continued)

Table 2. (Concluded)

Calendar year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Mean 1000 acre-ft±SD (X16.8 to ft^3/sec or X0.4757 to m^3/sec)											
1970-1979	291±	428±	694±	793±	705±	739±	869±	759±	573±	400±	300±	338±
	88	61	63	40	48	54	61	66	92	84	34	33
1980	304	387	1,056	1,121	964	1,145	1,247	1,164	982	879	760	715
1981	462	454	697	869	676	829	942	881	564	326	264	294
1982	330	492	653	851	658	618	763	638	501	380	219	264
1983	1,007	402	591	1,051	1,127	1,613	2,440	2,422	2,266	2,202	1,604	1,473
1984	1,728	1,657	1,741	1,609	1,662	1,932	2,012	1,835	1,668	1,595	1,498	1,527
1985	1,521	1,469	1,377	1,209	1,375	1,556	1,609	1,602	1,363	---	---	---
Imperial Dam												
1941-1949	1,115±	1,014±	1,049±	867±	969±	964±	889±	877±	892±	974±	1,045±	1,191±
	853	328	256	217	216	294	145	152	245	250	258	325
1950-1959	796±	683±	845±	654±	828±	795±	873±	849±	715±	644±	575±	655±
	364	264	323	236	247	190	123	130	183	218	228	306
1960-1969	319±	373±	590±	638±	578±	629±	719±	699±	533±	424±	305±	277±
	65	41	43	60	42	62	68	56	57	32	62	54
1970-1979	294±	355±	568±	656±	580±	578±	684±	648±	507±	397±	298±	326±
	71	45	57	30	44	39	46	52	63	63	33	22
1980	317	343	858	979	861	922	1,066	986	864	818	727	698
1981	504	368	602	736	579	624	745	726	506	345	257	277
1982	331	378	539	708	535	497	590	562	415	367	247	238
1983	862	448	505	840	960	1,339	2,226	2,320	2,142	2,219	1,609	1,456
1984	1,649	1,577	1,607	1,514	1,510	1,705	1,844	1,716	1,534	1,501	1,428	1,521
1985	1,474	1,374	1,274	1,073	1,166	1,348	1,422	1,424	1,315	---	---	---

Table 3. Annual sediment load through six stations along the lower Colorado River. Data from U.S. Department of the Interior (1987).

Calendar year(s)	Lee's Ferry	Grand Canyon	Littlefield	Hoover Dam	Parker Dam	Imperial Dam
	Sediment load (1,000 t)					
1941-1949	9,055±1,212	1,055±1,572	398±108	12,009±2,059	11,911±2,064	11,384±1,945
1950-1959	8,216±2,171	9,197±2,371	356±119	9,762±1,470	9,125±1,735	8,952±1,649
1960-1969	6,590±2,592	7,437±2,591	306±78	7,898±338	6,665±374	6,882±320
1970-1979	6,653±481	7,569±474	316±83	7,635±485	6,678±309	6,742±270
1980	8,056	9,155	658	10,425	10,375	9,751
1981	5,647	6,254	371	7,672	7,039	6,995
1982	6,722	7,241	435	6,886	6,172	6,076
1983	12,963	13,630	653	17,074	16,783	16,739
1984	12,715	13,960	422	17,423	16,992	17,548

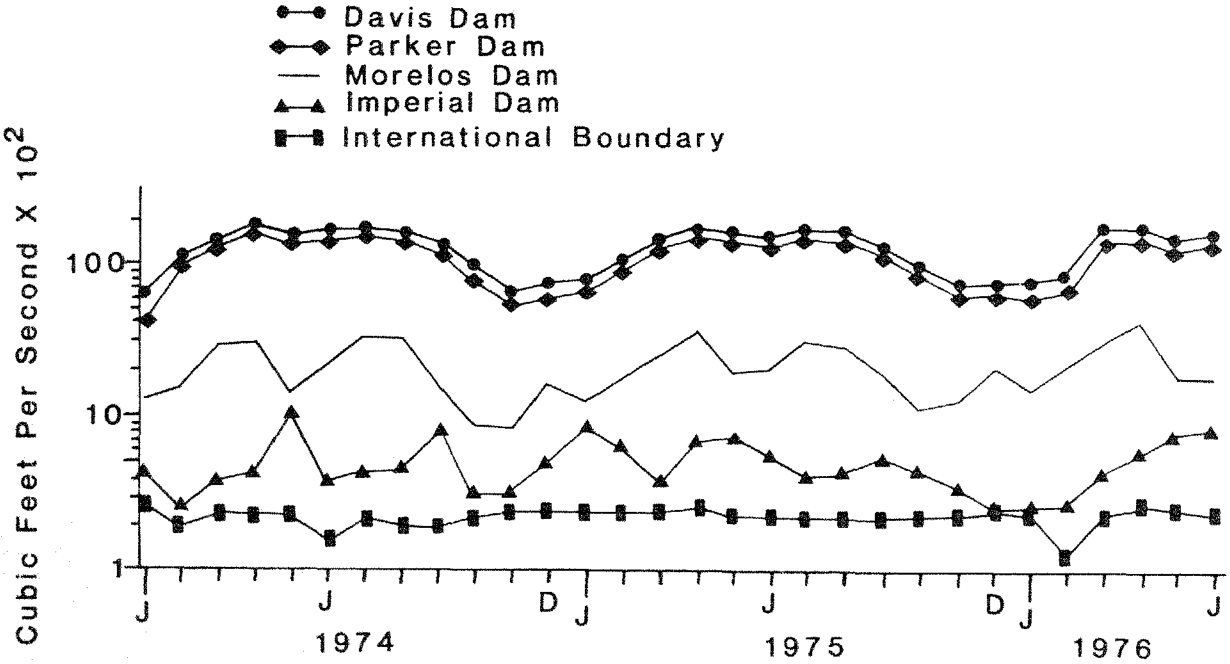

Figure 25. Patterns of monthly discharge of the lower Colorado River mainstream at various points between Davis Dam and the U.S.-Mexico Boundary, 1974 through 1976; compiled from U.S. Geological Survey. From Minckley (1979).

Delta since 1935. Two pumping stations on Lake Havasu, one on the west side of the lake sends water to southern California and the one on the east side to central and southern Arizona, draw much of the lower Colorado River water away from the mainstream. Groundwater supplies are declining in accessible aquifers along the lower Colorado River; however, the water table has dropped substantially less than in aquifers found in the metropolitan areas of central and southern Arizona (Lower Colorado River Comprehensive Framework Study 1971).

Future Hydrology

Future water demands will continue to outdistance supplies for the lower Colorado River region as a whole. Even with the Central Arizona Project, water tables are predicted to continue declining. The entire lower Colorado River region water supply will be deficient by at least 4.9 X 10^9 m^3 (4 million acre-ft) over projected demand by the year 2020 (Lower Colorado River Comprehensive Framework Study 1971). This figure does not include water losses that may be associated with future water-quality control nor the necessary losses that would be incurred to totally develop the region's water supply.

3.2 WATER QUALITY

Past Physicochemistry

Water quality along the lower Colorado River was probably as variable as the amount of flow before the closure of Hoover Dam (Minckley 1979). Deeper portions of backwaters and oxbow lakes may have been poorly oxygenated. Alternatively, backwaters may have been supersaturated with oxygen if there were large standing crops of phytoplankton and high nutrient loading. The highly fluctuating flows of the predam river resulted in highly variable concentrations of total dissolved solids (Figure 26). During low flows, concentrations of total dissolved solids became very high, as they do in many desert waters. The lower Colorado River is naturally salty, as many of the geologic formations in the basin were deposited, e.g., Las Vegas Wash, in marine or brackish water environments. This condition was exacerbated by drought and evaporation. Sulfates and sodium chloride are the prevalent salts in these natural formations. Oxbow lakes were subject to intense evaporation and were described by Grinnell (1914) as "lifeless alkali lakes" in their later stages of development (Ohmart et al. 1975).

Summer daytime water temperatures were estimated by Minckley (1979) to exceed 30 °C (86 °F), but approached 40 °C (104 °F) only when insolation was accompanied by high relative humidities (Deacon and Minckley 1974).

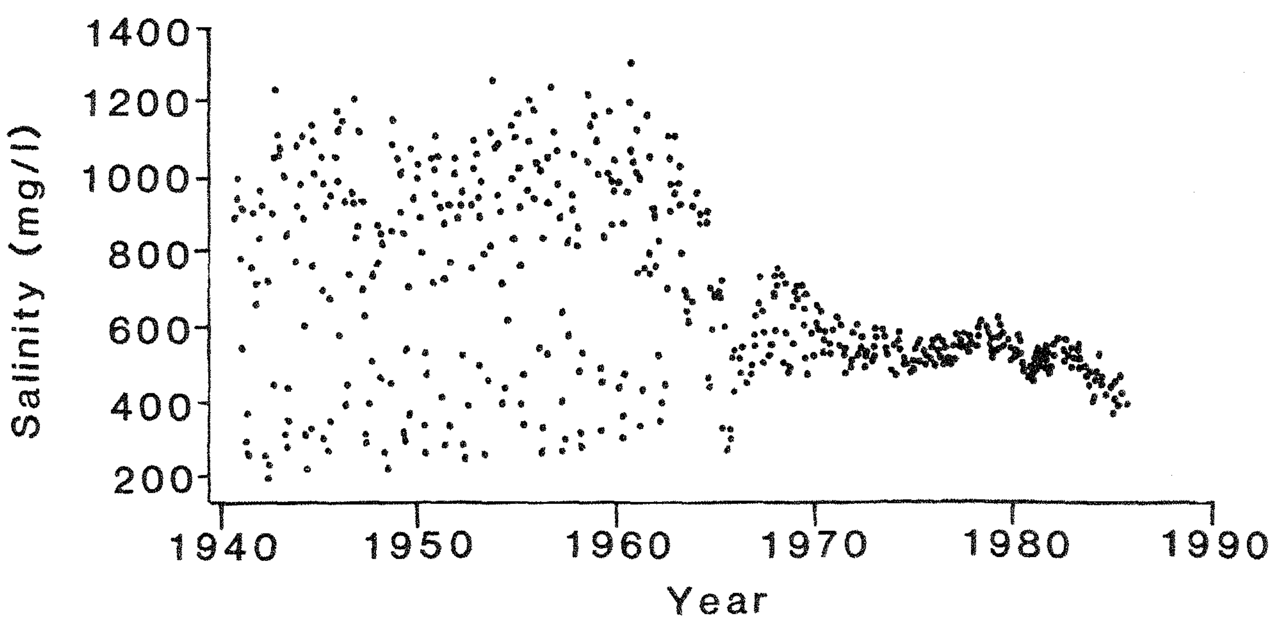

Figure 26. Monthly salinity levels below Lake Powell (1941-85). Adapted from U.S. Department of the Interior (1987).

Nighttime water temperatures declined rapidly because of low water vapor pressures.

Salinity

Increasing salinity levels since the construction of the major dams, including Glen Canyon Dam, have become the most serious problem concerning water managers on the lower Colorado River. Natural or background salinity has been changed by the development of water resources in two major ways: (1) by addition of salts from agricultural sources and (2) by the depletion of water along the mainstem.

Presently, concerns over salinity, other than in water delivered to Mexico, include all three lower basin States. In Arizona, there are two major concerns. First, the alkalinity in drinking water exceeds U.S. Public Health Services maximum levels around Parker Dam. Second, salinity in water delivered to Arizona through the Central Arizona Project may be too saline to be useful to those purchasing the water. In Nevada, Las Vegas Wash is not only a source for high salinity but also serves as a source of phosphorus and ammonia, all potentially detrimental to water quality for human use (U.S. Department of the Interior 1987). Lastly, in southern California, 65% of all water is from the lower Colorado River to irrigate 320,000 ha (800,000 acres) and to serve 12 million people. Because California is next to Mexico as the last water user of Colorado River water this region bears the brunt of all the salts concentrated upstream, which may result both in health safety and economic disaster for the region (U.S. Department of the Interior 1987).

Irrigated lands (0.6 million ha [1.5 million acres]) in the upper Colorado River basin contribute about 3.08 million t (3.4 millon tons) of total dissolved solids (TDS) per year (to what was about 4.81 million t [5.3 million tons] per year before agricultural development) at Lee's Ferry. This has raised the TDS level from 250 mg/l to 550 mg/l (U.S. Department of the Interior 1987). The lower Colorado River basin also contributes significant amounts of irrigation return flow from 160,000 ha (400,000 acres) from the mainstem and 0.6 million ha (1.5 million acres) from the Gila drainage. A dramatic rise in TDS is always found below Imperial Dam in the water destined for Mexico, with levels usually above 800 mg/l since the mid-1950's (Figure 27A).

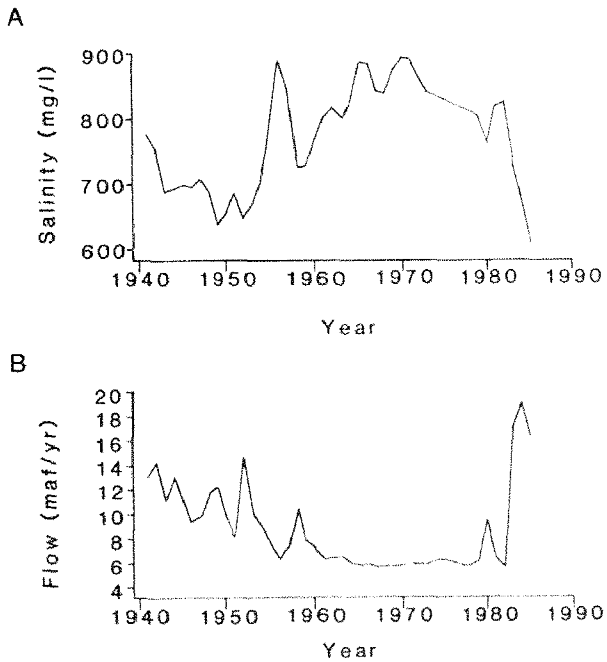

Figure 27. A. Mean annual salinity at Imperial Dam (1941-85). B. Mean annual flow at Imperial Dam (1941-85). Adapted from U.S. Department of the Interior (1987).

Water depletion, other than that for agriculture, is the more serious cause of rising TDS levels and, with decreasing agricultural expansion, will continue to become even more serious in the future. Consumptive use of water has and will reduce dilution of both natural and new sources of salt. Major sources of water loss, besides irrigation, include evaporation from reservoirs and channel, transbasin exports, and municipal-industrial diversions (Table 4). Transbasin exports begin in the upper basin at high elevations where TDS is characteristically low. This removal of high-quality water results in remaining low flows downstream which, in turn, increase TDS even though some salts are removed with the exports. Major depletions at Las Vegas, Lake Havasu (for both southern California and the Central Arizona Project), and, finally, at the All American Canal (for the Imperial Valley) in the U.S. all add to higher TDS levels for Mexico (Table 5). Additional withdrawals for industry, specifically oil shale mining, fluctuate in importance with changing oil prices; the higher energy prices become, the more withdrawal will occur. Water storage increases TDS levels in reservoirs through evaporation and decreased inflow rates. In addition, increased sedimentation in reservoirs may influence both salinity and the mix of other dissolved ions. Suspended sediment through physical and chemical degradation may continue to release salts and exchange ions (e.g., sodium for calcium). However, these salts and ion exchange processes may be isolated once they are settled out within the reservoir and release may be lower than that found in the breakdown processes in a natural riverine environment. Reservoirs also significantly reduce peak flows downstream which, in turn, decreases salt flushing. Additional salt loads are produced from erosion after torrential rains, but the total input is probably low.

Salinity concentrations at Imperial Dam decreased steadily from 1970-1979, dropped notably in 1980, increased sharply in 1981-1982, and dropped again in 1983-1984 (Figure 27A). The 1970-1980 salinity levels show the buffering of annual fluctuations in salinities due to the effect of nearly 61.7 billion m^3 (50 million

Table 4. Average water use in the Colorado River basin for 1976-1980 (in 1,000 acre-ft). Data from U.S. Department of the Interior (1987).

Type of use	Upper basin	Lower basin
Reservoir evaporation and channel losses	758	1,682
Irrigated agriculture	1,984	5,180
Municipal and industrial	178	453
Fish, wildlife, and recreation	0	50
Transbasin exports	3,647	11,604

Table 5. Colorado River depletion projections. Units are 1,000 acre-ft/yr. From U.S. Department of the Interior (1987).

Lower basin projects	1985	1990	2000	2010
Nevada				
Las Vegas Valley	78	143	203	225
Boulder City, NV	5	6	8	8
Lake Mead National Recreation Area	1	1	1	1
Miscellaneous users above Hoover Dam	1	1	1	1
Mohave Steamplant, Southern California Edison Co.	6	17	22	0
Fort Mohave Indian Reservation	0	4	8	8
Laughlin and miscellaneous users below Hoover Dam	1	5	7	7
TOTAL	92	178	250	250
Arizona				
Imperial Wildlife Refuge	13	13	13	13
Havasu Wildlife Refuge	37	37	37	37
Fort Mohave Indian Reservation	36	60	60	60
Kingman, Boulder Canyon Project	0	0	9	18
Mohave Valley Irrigation and Drainage District	24	30	41	41
Lake Havasu Irrigation and Drainage District	14	14	14	14
Central Arizona Project	54	1,515	1,488	1,464
Colorado River Indian Reservation	346	383	398	398
Cibola Wildlife Refuge	17	17	17	17
Gila Project	450	450	450	450
Wellton-Mohawk Division				
Yuma Mesa Division				
City of Yuma	10	13	18	23
Yuma Project and Yuma Auxiliary Project	212	212	212	212
Cocopah Indian Reservation	2	2	2	2
Other uses	83	54	41	51
TOTAL	1,298	2,800	2,800	2,800
California				
City of Needles	3	1	1	1
Metropolitan Water District	800	518	497	497
Fort Mohave Indian Reservation	9	9	9	9
Chemehuevi Indian Reservation	3	5	8	8
Colorado River Indian Reservation	12	15	33	33
Palo Verde Irrigation District	423	423	423	423
Yuma Project				
Indian Unit	24	24	24	24
Bard Unit	35	30	30	30
Imperial Irrigation District	2,943	3,029	3,029	3,029
Coachella Valley Water District	344	344	344	344
Other uses	27	2	2	2
TOTAL	4,623	4,400	4,400	4,400

acre-ft) of reservoir storage. With reservoir storage on the Colorado River near capacity, discharges from Hoover Dam increased from 9.5 billion m^3 (7.7 million acre-ft) in 1979 to 13.7 billion m^3 (11.1 million acre-ft) in 1980, diluting the salinity at Imperial Dam temporarily (U.S. Department of the Interior 1987). Normal flows in 1981 and 1982 resulted in rebounding salinity levels. Extremely high releases during 1983 and 1984, combined with lowered salinities in storage, caused salinity at Imperial Dam to drop again (Figure 27B). Salinity levels remained low through to 1986; however, salinity is expected to increase quickly back to 800 mg/l or more as "normal" flows resume.

A more detailed study was conducted by Minckley (1979) in the mid-1970's to compare various locations and salinity levels on the lower Colorado River and adjacent backwaters. Electroconductance (a measure directly correlated with TDS and salinity) in the mainstream averaged about 900 µmhos/cm at 25 °C (77 °F) in the higher portions of the lower Colorado River (Figure 28). Electroconductance remains at about 1,100 µmhos/cm to just above the Gila River confluence. Below the Colorado-Gila confluence, conductance substantially increases to above 4,000 µmhos/cm. High total dissolved solid levels in the Colorado River below the Gila River confluence presently are delivered to Mexico; however, construction of the Yuma Desalinization Plant will lower these levels.

Backwaters were typically higher in electroconductance than adjacent mainstream sections along the entire river, with highest conductance found at Hunter's Hole (@ 8,000 µmhos/cm) south of Yuma and at Moovayla Pond (@ 15,600 µmhos/cm) near Parker Dam. Backwaters are subject to greater evaporation than inflow, and are also subject to intermittent inflow of dissolved ions from storm events that enter from desert washes. Canals resemble the mainstream in electroconductance. Drains often are more saline (@ 2,000 µmhos/cm) than the mainstream as they carry irrigation runoff, which has leached salts from agricultural fields.

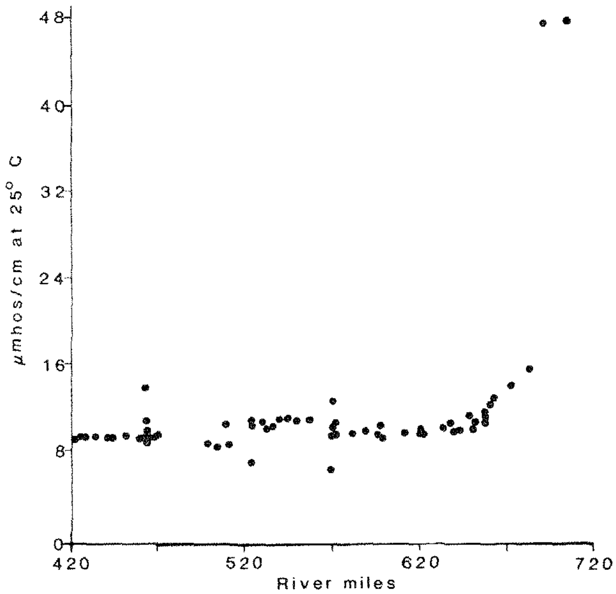

Figure 28. Means of conductance (µmhos/cm at 25 °C) upstream to downstream in the Colorado River mainstream, each dot represents a mean value for a location, ranging from 7 to more than 50 samples for each mean. From Minckley (1979).

River Laws and Salinity Control

Eight Federal documents set water appropriations and quality standards on the lower Colorado River. The major focuses of these documents are on salinity controls and water allocations among basin States and Mexico. These two focuses are intimately intertwined as amount of water flow is inversely related to salinity levels.

There are four documents that establish water allocations. The Colorado River Compact of 1922 divided water between upper and lower basins. The Upper Colorado River Basin Compact of 1948 divided water among the four upper basin States. Water allocation among the three lower basin States was not divided until the U.S. Supreme Court decision in 1964 on State of Arizona versus California et al. The fourth appropriation document is the treaty signed in 1944 between the United States and Mexico establishing 1.7 billion m^3 (1.4 million acre-ft) of Colorado River water to go to Mexico annually.

There are four documents that establish controls on salinity levels and other water quality attributes. The Water Quality Act of 1965 (P.L. 89-234) established the Environmental Protection Agency, which regulates national standards and requires basin States to maintain salinity levels at or below these standards. The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) established numerical standards for salinity, which led to the formation of the Colorado River Basin Salinity Act of 1974 (P.L. 93-320). This was also in response to the 1973 agreement between the United States and Mexico in Minute No. 242 entitled Permanent and Definitive Solution to the International Problem of the Salinity of the Colorado River. Minute No. 242 specified salinity levels of water going into Mexico to be no greater than 115±30 ppm over annual average salinities at Imperial Dam. P.L. 93-320 also called for works of improvement to enhance the quality of Colorado River water to Mexico (Title I, Yuma Desalinization Plant) and for reports on salinity levels every 2 years, with compliance to numeric criteria ensured through to the year 2005 (Title II, as amended by P.L. 98-569 in 1984).

Presently, standard maintenance of salinity levels approved in 1975 by all parties are in effect. Average TDS below Hoover Dam needs to be maintained at 723 mg/l. Below Parker, the level of TDS to be maintained is 747 mg/l. Finally, at Imperial, TDS levels need to be maintained at no more than 879 mg/l. These levels have been maintained since the floods of 1983.

Maintenance of the above levels is provided for by Title I of P.L. 93-320 with the following features: (1) lining of irrigation delivery systems, (2) deep well injection of brine, (3) plugging of flowing brine wells, (4) control of erosion in arid lands, (5) controlling deep percolation from farm management systems, and (6) prevention of pumped saline groundwater (from Las Vegas Wash, lower Virgin River) mixing with surface flows. The major feature from Title I is the construction of the Yuma Desalinization Plant on a 24-ha (60-acre) tract 9.6 km (6 mi) west of Yuma. The main outlet drain extension will carry saline drainage water to the plant. Desalted water will then be delivered back to the nearby Colorado River for delivery to Mexico. The primary purpose of the plant is to upgrade the quality of drainage water from the lower Gila River (Wellton-Mohawk Irrigation and Drainage District). The Yuma Desalinization Plant was specifically called for in Minute No. 242, with completion slated for 1989-1990. Other features in Title I include (1) concrete lining the Coachella Canal, (2) protective and regulatory pumping in the Yuma area which shares its aquifer with Mexico, and (3) improving soil-water conservation practices on the Wellton-Mohawk Irrigation and Drainage District.

Besides the Wellton-Mohawk Irrigation and Drainage District on the Gila

River, there are two large management units of concern to salinity control on the lower Colorado River. In 1964, the U.S. Supreme Court allocated water to the Colorado River Indian Reservation to irrigate 43,035 ha (107,588 acres) of which 39,750 ha (99,374 acres) were in Arizona and 3,285 ha (8,213 acres) in California. Maximum diversion of 8.8 billion m^3 (717,147 acre-ft) was allowed. By 1983, 30,614 ha (76,536 acres) were being irrigated with Colorado River water diverted at Headgate Rock Dam. It is doubtful that the area under irrigation will increase in the near future to the authorized 43,000 ha (107,500 acres), given the present farm market situation. Colorado River water is delivered by 320 km (200 mi) of canals and laterals to this land, while irrigation return flows are collected in a 160-km (100-mi) drainage system to the river.

The second large management unit of concern is the Palo Verde Irrigation District, which has water diverted at the Palo Verde Diversion Dam. Colorado River water moves through a network of 405 km (253 mi) of canals and laterals to serve 49,850 ha (123,130 acres). Irrigation return flows are collected in a 238-km (149-mi) drainage system. Since 1951, return flows have contained about 10% more salt than the water originally diverted from the river in the Palo Verde Irrigation District, although these levels have decreased and stabilized recently. This increase in salt load appears to have resulted primarily from displacement of ancient saline groundwater by applications of fresh Colorado River water. Thus, work to control salinity increases has centered on ways to minimize the added increment of salt that is contained in irrigation return flows.

Salinity control projects prevented 115,008 t (126,800 tons) of salt per year from entering the system (U.S. Department of the Interior 1987). By 2010, salinity control units will need to prevent slightly more than a million tons per year of salt from entering the Colorado River (Table 6). The Yuma Desalinization Plant is among the more important features to be used to reduce Colorado River salt levels.

Present-Day Physicochemistry

Information on the physicochemical nature of lower Colorado River water is based on data collected by Everett et al. (1973), Broadway and Herrgesell (1978) and Minckley (1979). Temperatures are most constant year-round just below Davis Dam with a range from 12 to 16 °C (54 to 61 °F). Below Parker Dam, temperatures range from 21.5 to 25 °C (71 to 77 °F) in summer to 12 °C (54 °F) in winter. Cold water below Davis Dam is contributed from the hypolimnion of Lake Mohave, while warmer water below Parker Dam is contributed by epilimnetic pen stock intake from Lake Havasu (Minckley 1982). Stratified summer temperatures in Lake Havasu vary from 27.5 °C (81.5 °F) at the surface to 21 °C (70 °F) in 16 m (52 ft) of water. Temperatures in the lower reaches of the river are more constant and generally warmer than those the upper reaches. Summer temperatures peak near 30 to 31 °C (86 to 88 °F) during midday and cool to 26 to 29 °C (79 to 84 °F), while winter temperatures range from about 12 to 17 °C (54 to 63 °F) at midday. Backwaters are typically 2 to 4 °C warmer in summer and cooler by the same range during winter than mainstream temperatures. The highest water temperatures recorded by Minckley (1979) exceeded 40 °C (104 °F) within drains in the Limitrophe Division; the coolest recorded temperature (8 °C [46 °F] in winter) was in backwaters in the Yuma Division.

Table 6. Salinity projections for the Colorado River basin. From U.S. Department of the Interior (1987). The P≤0.2 level of salinity is based on the highest 3 of 15 CRSS runs and is an estimate of the salinity level which may be exceeded by about 20% of the time.

Station	Present (1974-1984)		Future (2010)		
	Flow (1,000 acre-ft)	Salinity (mg/l)	Flow (1,000 acre-ft)	Salinity (mg/l)	Salinity P≤0.2 (mg/l)
Green River near Green River, WY	1,359	325	1,261	319	512
Green River near Greendale, UT	1,697	483	1,627	406	569
Yampa River near Maybell, CO	1,237	176	1,129	155	196
Duchesne River near Randlett, UT	448	721	211	1,795	2,938
White River near Watson, UT	550	391	513	454	579
Green River at Green River, UT	4,691	456	3,987	555	699
San Rafael River near Green River, UT	117	1,976	104	1,212	1,873
Colorado River near Glenwood Springs, CO	1,692	261	1,368	424	678
Colorado River near Cameo, CO	2,951	404	2,811	403	565
Gunnison River near Grand Junction, CO	1,938	566	1,845	624	980
Dolores River near Cisco, CO	749	784	619	857	1,898
Colorado River near Cisco, CO	5,508	590	4,826	717	1,170

(Continued)

Table 6. (Concluded)

Station	Present (1974-1984) Flow (1,000 acre-ft)	Present (1974-1984) Salinity (mg/l)	Future (2010) Flow (1,000 acre-ft)	Future (2010) Salinity (mg/l)	Future (2010) Salinity $P \leq 0.2$ (mg/l)
San Juan River near Archuleta, NM	866	163	643	186	233
San Juan River near Bluff, UT	1,592	462	1,202	1,052	1,761
Colorado River at Lees Ferry, AZ	10,867	534	9,879	698	843
Colorado River near Grand Canyon, AZ	11,152	581	10,247	732	882
Virgin River at Littlefield, AZ	221	1,604	134	1,608	2,114
Colorado River below Hoover Dam	10,490	670	9,755	794	904
Colorado River above Parker Dam	n/a	n/a	9,386	823	936
Colorado River below Parker Dam	9,514	691	7,198	826	952
Colorado River at Imperial Dam	8,450	793	6,249	963	1,123

Dissolved oxygen concentrations remain above 60% saturation at all times. The highest saturation levels are typically found during midafternoon (e.g., increased photosynthetic activity) and in areas with low turbidity. Lowest oxygen saturation levels are found where hypolimnion discharge is greatest and in areas of turbulent waters such as the reach below Davis Dam. The greatest variation in measured oxygen saturation levels is in the lowest portions of the river, especially where decomposing organic matter is highly concentrated in the channel below Morelos Dam (Table 7). Oxygen levels often exceed 100% saturation year-round on the entire river (Minckley 1979).

Backwaters have high oxygen saturation levels at the surface, but have very low levels (lowest recorded in the whole system) at depths of $\geq$4 m

Table 7. Dissolved oxygen concentrations (in percentage saturations) for 30 sampling periods on the mainstream Colorado River, 1974-75. Each mean is for 24 consecutive hours of samples, excepting River Mile 683.7 (Limitrophe Division), which is based on 12 samples at 2-hr intervals. In each instance, ranges represent nighttime minima and daytime maxima. Dates are month/day/year. From Minckley (1979).

Divisions	River mile	Dates	Means	Ranges
Mohave Valley	428.3	9/30/75	79.2 ± 2.6	74.0- 92.0
	453.5	10/15/75	113.8 ± 2.0	89.0-130.1
Topock Gorge	465.2	10/10/75	102.6 ± 2.3	90.0-111.7
Havasu[a]	510.3	6/7/74	88.4 ± 5.5	76.6-135.5
	524.4	6/11/74	103.2 ± 3.3	86.9-111.6
Parker	524.5	6/11/74	86.3 ± 3.7	72.8-101.0
	531.4	6/12/74	103.9 ± 5.9	81.8-120.9
	536.0	6/17/74	117.4 ± 8.5	87.2-151.7
	539.4	6/21/74	94.8 ± 4.8	81.3-111.7
	545.0	6/24/74	74.7 ± 1.9	68.3- 82.7
	550.0	6/26/74	74.7 ± 2.8	64.6- 89.9
	557.9	6/29/74	75.3 ± 1.8	64.1- 81.5
	568.0	7/2/74	66.5 ± 1.5	59.1- 71.3
	524.5	7/3/74	63.5 ± 2.8	55.7- 78.3
Palo Verde	570.8	3/1/75	108.4 ± 1.1	102.8-114.8
	581.5	2/28/75	106.6 ± 2.2	92.5-114.3
	590.0	3/6/75	97.2 ± 4.1	79.1-118.1
Cibola	600.0	3/7/75	89.0 ± 1.9	80.3- 93.8
	610.0	3/15/75	110.0 ± 3.9	88.6-120.1
	620.0	3/20/74	104.9 ± 4.2	98.2-114.3
Imperial	632.9	8/8/75	101.6 ± 2.1	92.1-111.1
	639.0	6/26/75	110.0 ± 2.3	102.7-119.7
	650.0	6/24/75	124.1 ± 2.9	101.9-123.2
Laguna	662.5	6/9/75	121.5 ± 1.9	105.9-120.8
Yuma	662.7	6/9/75	119.4 ± 2.0	103.3-118.8
	671.9	6/5/75	113.6 ± 3.2	99.6-132.6
	672.1	6/5/75	113.4 ± 4.6	88.4-128.6
	683.0	6/7/75	105.8 ± 2.7	99.4-122.0
Limitrophe	683.7	9/5/74	106.0 ±22.5	51.5-160.0
	704.0	8/16/74	91.3 ± 8.4	65.9-125.5

[a] Includes only samples from the flowing portion of Havasu Division.

(≥13 ft). Canals and drains resemble the mainstream in having diurnal cycling of dissolved oxygen saturations, with averages often exceeding 100%. Where weirs increase turbulence and where organic material is prevalent, saturation levels are substantially lower.

Transparency of the euphotic zone (zone of production) is highly variable throughout the system (Broadway and Herrgesell 1978). Secchi disks were used to assess light penetration influenced by absorption characteristics of the water. Turbidity of the water (dissolved and particulate matter concentrations) is measured by transparency. Generally, waters at lentic stations were twice as transparent as those in nearby lotic areas, with turbidity 1.5 times higher in running water. Greater turbidity and lower transparency occurred with increasing distance downstream along mainstream lotic habitats.

Hydrogen ion concentrations (i.e., pH) generally range slightly basic (average 7.9 to 8.2, range 7.2 to 9.2; Minckley 1979). Lowest pH readings are associated with water inflow from drains or with interchanges of water between the mainstream and large backwaters. These values are related to nocturnal reducing conditions accompanying decomposition of organic material. Diurnal fluctuations, when present, are parallel to oxygen saturation levels reflecting production and respiration of photosynthetic plants during day and night, respectively. Levels of pH in backwaters range 6.6 to 8.0 and are less variable than in the channel.

Phosphate-phosphorus (PO_4-P) and nitrate-nitrogen (NO_3-N) are often used as agricultural fertilizers. Levels of these nutrients in the lower Colorado River water were measured by Minckley (1979). Phosphate-phosphorus levels were parallel to salt concentration levels from high to low reaches of the lower Colorado River, with significantly higher concentrations nearest the Colorado River Delta (Table 8). Backwaters had significantly lower concentrations of PO_4-P than the mainstream, implying some depletion of this nutrient by plants in lentic habitats (Minckley 1979). Concentrations of PO_4-P were far higher in canals and drains than in the mainstream, reflecting the influx of fertilizers from agricultural lands. Concentrations of NO_3-N were higher than PO_4-P in the higher reaches of the lower Colorado River, but were equal to PO_4-P in the Imperial Dam area (Minckley 1979). Broadway and Herrgesell (1978) measured four forms of nitrogen, including nitrite (NO_2^--N) and ammonia (NH_3), and found the highest concentrations for all forms present at the Palo Verde Agricultural Drain and Palo Verde Oxbow Lake; however, none were present in high levels.

The modern lower Colorado River is becoming more oligotrophic through time because nutrients are increasingly being trapped behind upstream reservoirs (Everett et al. 1973; Broadway and Herrgesell 1978). Lakes Powell and Mead contribute few nutrients downstream, because most nutrients are tied up in sediment and in blooms of phytoplankton, primarily green algae. Lakes Mohave and Havasu are still somewhat productive because of nutrient flow from Lake Mead (originating at Las Vegas Wash and the Bill Williams River, respectively; Broadway and Herrgesell 1978). Downstream of Parker Dam free-nutrient levels become very low except where there is agricultural runoff as at Poston Wasteway, Palo Verde Drain, and the Gila River confluence (Broadway and Herrgesell 1978; U.S. Department of the Interior 1987). Since most PO_4-P is associated with suspended sediments, sedimentation behind Glen Canyon Dam effectively retains most of this nutrient, which historically flowed downstream. Suspended sediments and PO_4-P inputs from the Grand Canyon rapidly drop out in the upper end of Lake Mead. The Virgin River inflows to Lake Mead are minor sources of PO_4-P to the system. PO_4-P retention in Lake Mohave is low

Table 8. Concentrations (in mg/l) of phosphate-phosphorus and nitrate-nitrogen in waters from the lower Colorado River, 1974-76. Dates are month/year. From Minckley (1979).

Division	Dates	Number of samples	Phosphate-phosphorus	Number of samples	Nitrate-nitrogen
Mohave Valley	9/75-10/75				
Mainstream		53	0.056±0.012	55	0.171±0.022
Backwater		6	0.333±0.021	6	0.165±0.036
Topock Gorge	10/75				
Mainstream		52	0.106±0.025	51	0.164±0.013
Backwater		3	0.047±0.007	3	0.185±0.005
Havasu	6/74, 1/76				
Mainstream		77	0.071±0.012	47	0.147±0.005
Backwater[a]		14	0.069±0.003	14	0.136±0.007
Backwater		13	0.045±0.019	--	----
Parker	6/74-7/74				
Mainstream		271	0.089±0.007	--	----
Palo Verde	2/75-3/75				
Mainstream		81	0.084±0.017	--	----
Backwater		3	0.008±0.004	--	----
Cibola	3/75				
Mainstream		75	0.078±0.013	--	----
Backwater		19	0.091±0.032	--	----
Imperial	6/75, 8/75				
Mainstream		85	0.120±0.018	90	0.114±0.008
Backwater		43	0.098±0.023	40	0.062±0.018
Laguna	6/75				
Mainstream		30	0.089±0.024	--	----
Backwater		5	0.147±0.039	--	----
Yuma	6/75				
Mainstream		75	0.129±0.018	--	----
Backwater		1	0.030±0.000	--	----
Limitrophe	8/74-9/74				
Mainstream		55	0.182±0.061	--	----
Backwater		28	0.066±0.021	--	----

[a]Samples from the main body of Lake Havasu.

due to rapid flushing of the reservoir. PO_4-P from Las Vegas Wash is bioavailable and contributes most of this nutrient in the middle portion of the Colorado River. Recently, efforts to fertilize portions of Lake Mead have been undertaken. Results from these pilot programs have been reported as successful, but they are labor intensive and expensive. Concerns are voiced relative to effects on water quality from downstream users.

Las Vegas Wash inflows of PO_4-P have been decreasing recently and can be expected to decrease productivity in Lakes Mohave and Havasu. Productivity in Lake Mead has undergone a steady decline since the late 1970's when PO_4-P began to decrease as a result of the commencement of tertiary wastewater treatment in the Las Vegas Valley. This appears to be a major factor responsible for recent declines of sport fisheries at Lake Mead. Similar reductions in the Lake Mohave fisheries, including native razorback sucker (<u>Xyrauchen texanus</u>), may involve PO_4-P declines as well.

<u>Biomass Productivity</u>

Primary productivity as measured by C^{14} (carbon fixation rates) concentrations is low throughout the system with high values found only near inlets into the mainstream (Broadway and Herrgesell 1978). The highest single value for primary productivity recorded by Broadway and Herrgesell (1978) was at the Bill Williams Arm of Lake Havasu where a source of PO_4-P occurs. The most consistent reach of high primary productivity was immediately below the Colorado-Gila River confluence, again, where PO_4-P was at relatively high concentrations (see also Marsh and Minckley 1985, 1987). Generally, among the lotic stations of Broadway and Herrgesell (1978), the order of highest to lowest primary productivity was from downstream to upstream with the Gila-Colorado River confluence, Morelos, Laguna, Lake Moovayla, Needles, Topock, Palo Verde Agricultural Drain, Taylor Ferry, and Cibola National Wildlife Refuge (Adobe Ruin). Among lentic habitats the geographical order of primary productivity was less generalized downstream to upstream, with the highest to lowest values being the Bill Williams Delta, Ferguson Lake, Imperial National Wildlife Refuge (Taylor Lake), Lake Havasu, Palo Verde Oxbow Lake, Cibola Lake, and Senator Wash Reservoir.

Measuring standing phytoplankton biomass by chlorophyll <u>a</u> concentrations demonstrated a trend similar to primary productivity, with increasing concentration from upstream to downstream reaches (Table 9) (Broadway and Herrgesell 1978; Minckley 1979). Very high chlorophyll <u>a</u> concentrations were found in lentic habitats in Minckley's (1979) study, especially at Moovayla Pond, Palo Verde Oxbow, and Hunter's Hole. These lentic habitats are isolated from the main channel and may receive water, often carrying nutrients, from inflow drain.

Low productivity levels would be expected in large unaltered dynamic system such as the Colorado River before dams. Impoundments and resulting slower flows in the modern river, especially in the lower reaches, however, should have had higher levels of productivity than actually found (Broadway and Herrgesell 1978). Slow-moving lower reaches, where agricultural return flows contain high PO_4-P and NO_3-N loads, should be more productive, but insecticides, herbicides, and high turbidities may greatly suppress phytoplankton abundance. As mentioned earlier, very little nutrient or organic matter can filter through the entire system. Thus, the Colorado River is dependent primarily

Table 9. Concentrations of chlorophyll _a_ (mg/m^3) in water samples from the lower Colorado River, 1974-76. Dates are month/year. From Minckley (1979).

Locations	Dates	Number of samples	Means	Ranges
Mohave Valley	9/75-10/75			
Mainstream		67	3.10 ± 0.76	>0.00- 21.84
Backwater		7	3.28 ± 1.91	0.73- 8.53
Topock Gorge	10/75			
Mainstream		25	2.65 ± 0.44	0.35- 4.44
Backwater		10	3.14 ± 3.06	0.37- 16.72
Havasu	6/74, 1/76			
Mainstream		83	1.04 ± 0.21	>0.00- 4.68
Backwater[a]		53	2.29 ± 0.30	0.17- 4.58
Backwater		19	3.38 ± 1.28	0.63- 9.61
Backwater[b]		4	87.65 ±10.65	78.94-103.18
Parker	6/74-7/74			
Mainstream		274	1.09 ± 0.41	>0.00- 12.87
Palo Verde	2/75-3/75			
Mainstream		74	2.77 ± 0.63	0.51- 6.34
Backwater		18	20.41 ±14.46	3.09-122.29
Cibola	3/75			
Mainstream		75	2.67 ± 0.45	>0.00- 55.66
Backwater		23	6.96 ± 1.91	1.36- 18.00
Imperial	6/75, 8/75			
Mainstream		87	3.03 ± 0.63	>0.00- 26.09
Backwater		40	3.87 ± 1.08	0.28- 11.09
Laguna	6/75			
Mainstream		35	3.68 ± 0.84	0.33- 8.58
Backwater		6	7.90 ± 1.42	4.37- 9.02
Yuma	6/75			
Mainstream		76	4.27 ± 0.40	0.93- 61.07
Limitrophe	8/74-9/74			
Mainstream		43	9.29 ± 3.76	>0.00- 27.36
Backwater		40	47.53 ± 6.88	2.84- 99.86

[a]Samples from open waters of Lake Havasu.
[b]Samples from Moovayla Pond, a cutoff from the main river.

upon autochthonous buildup and not on allochthonous material, except in a few areas experiencing agricultural runoff (Minckley 1982). Almost all silt and associated nutrients settle behind the major dams.

Broadway and Herrgesell (1978) observed one exception to the otherwise dominance of autochthonous buildup. Hurricane Kathleen, during October 1976, resulted in heavy rains which swelled desert washes and the

Bill Williams River. Upstream reaches of the river experienced their highest levels of primary productivity during this period, while production rates in the lower reaches were generally low. Lakes Mohave and Havasu apparently had a buffering effect of lateral silt input from storm waters, and the storm itself was less intense in the upstream reaches. This resulted in reduced turbidity and higher light levels upstream of Parker Dam. In the meantime, very turbid waters and heavier cloud cover occurred downstream of Parker Dam. All this acted to increase the use of nutrients from surface runoff in the upstream reaches while the lower reaches experienced decreased use of nutrients (Broadway and Herrgesell 1978). Thus, the rare large storm that comes to the lower Colorado River can have a well-pronounced, although punctuated, effect on biomass production in the system.

Everett et al. (1973) noted a shift in phytoplankton and zooplankton taxa among Lakes Powell, Mead, and Havasu. Lake Powell is characterized by green algae, which supports a healthy grazing crustacean community (Table 10). On the other extreme, Lake Havasu is dominated by nonedible filamentous cyanobacteria and dinoflagellates. Lake Mead is intermediate in both location and biota. Thus, Lake Havasu has high phytoplankton biomass in cyanobacteria, but this represents a trophic "dead end" for a stable food chain. Zooplankton taxa were also found to be in very low densities below Parker Dam along the mainstream above the Gila River confluence (Table 11) (Everett et al. 1973). Reductions in copper, cobalt, and manganese as micronutrients may cause serious declines in productivity and are associated with increases in cyanobacteria and benthic diatoms (Table 12).

Effects of physicochemical attributes of the modern river are caused by large numbers of human-made modifications that reverberate through the aquatic trophic levels. The presence and operations of dams have altered flows, modified temperatures, and influenced nutrient circulation in the system. Increased transparency, lower water temperatures, and nutrient entrapment in the upper reaches contrasts sharply with higher turbidity, warmer water temperatures, higher TDS, and agricultural input of PO_4-P of lower reaches. All of these factors influence not only the food base, but also the physiological environment for fish. These interrelationships are discussed further in Chapter 9.

Toxins

Heavy metal and pesticide-herbicide pollution is a serious concern along the lower Gila and Colorado Rivers (Kepner 1986; Radtke et al. 1988). Selenium levels, organochlorine pesticides, and heavy metals were recently quantified in a variety of biotic and abiotic matrices. Findings indicate elevated concentrations of selenium that approach the threshold of reproductive failure in fish (Tables 13 and 14). Centrarchid fish are very sensitive to selenium exposure, and changes in their population levels may serve as good indicators of high concentrations of this element (Radtke et al. 1988). One liver sample from a Yuma clapper rail (collected at Mittry Lake), an endangered (Federal) species, contained nearly double the normal levels of selenium and was similar to values obtained from bird livers at Kesterson National Wildlife Refuge, CA, where very high selenium levels have been associated with reproductive failure (Ohlendorf et al. 1986; Radtke et al. 1988).

Table 10. Planktonic biota in three lakes on the Colorado River. From Everett et al. (1973).

	Lake Powell	Lake Mead	Lake Havasu
Cladocera	***	**	*
Copepods	***	*	*
Young crustacea	***	*	*
Dinoflagellates	*	**	***
Rotifers	*	**	**
Diatoms	*	**	0
Green algae	***	**	*
Small blue-green	**	**	0
Long filaments blue-green	0	0	***

*Small, few, not dominant.
**Large, few, not dominant.
***Large, many, dominant.

Table 11. Major zooplankton (number/m^3 for 20 m column, river samples are number/m^3), March 20-26, 1970. From Everett et al. (1973).

	Station			
Zooplankton	Lake Mohave	Lake Havasu	River at Ehrenberg	River at Yuma
Cylopoida	170,000	88,000	300	0
Calanoida	64,000	58,000	3,000	0
Nauplii	161,000	160,000	300	3,000
Daphnia	700,000	536,000	12,000	700
Daphnia young	136,000	26,000	0	0
Bosmina	63,000	40,000	1,000	0
Asplanchna	123,000	217,000	3,000	3,000

Table 12. Colorado River water chemistry. From Everett et al. (1973).

		Station					
		Las Vegas Wash	Willow Beach	Lake Mohave	Lake Havasu	Blythe	Yuma Prison
Ca	(ppm)	91.0	90.0	91.0	90.0	93.0	126.0
Mg	(ppm)	36.0	34.0	34.0	35.0	34.0	48.0
Na	(ppm)	108.0	103.0	107.0	106.0	109.0	233.0
Cl^+	(ppm)	108.0	100.0	104.0	100.0	104.0	308.0
SO_4	(ppm)	320.0	310.0	320.0	310.0	320.0	400.0
K	(ppm)	5.8	5.9	5.3	5.9	5.0	6.3
PO_4	(ppm)	0.02	0.02	0.0	0.01	0.034	0.024
F^-	(ppm)	0.36	0.36	0.38	0.45	0.45	0.63
NO_3	(ppm)	1.0	0.24	1.5	1.6	1.7	1.5
SiO_3	(ppb)	7.0	10.0	8.5	8.5	7.0	16.0
B	(ppb)	0.26	0.26	0.25	0.26	0.25	0.46
Mn	(ppb)	0.0	0.0	0.0	0.0	36.0	73.5
Fe	(ppb)	18.7	3.75	46.2	26.2	0.0	191.2
Cu	(ppb)	5.3	2.1	0.0	0.0	0.0	0.0
Zn	(ppb)	18.5	3.8	29.0	53.2	71.0	35.0
Co	(ppb)	0.0	0.0	0.0	0.0	0.0	0.0

Table 13. Lower Colorado River selenium data, National Contamination Biomonitoring Program, 1972-1980. BKS = black crappie (*Pomoxis nigromaculatus*), BGS = bluegill (*Lepomis macrochirus*), C = carp (*Cyprinus carpio*), CHC = channel catfish (*Ictalurus punctatus*), LMB = largemouth bass (*Micropterus salmoides*), RBT = rainbow trout (*Salmo gairdneri*), SMU = striped mullet, TIL = tilapia (*Tilapia* spp.), and YEB = yellow bullhead (*Ictalurus natalis*). Adapted from Metz (1985).

Location	Mean±1 SD (ppm)	Range (ppm)	n	Species
Topock Marsh[a]	3.10±0.28	2.90-3.30	2	C
Lake Havasu[a]	2.53±1.59	1.40-3.65	10	BKS, C, LMB, YEB
Imperial Reservoir[a]	2.51±0.86	0.44-3.60	11	BGS, C, LMB
Lake Powell[a]	2.07±0.89	0.36-3.00	11	C, LMB, RBT
Yuma	1.55±0.19	1.37-1.75	3	C, LMB, SMU
Poston Main Drain	1.34±0.34	1.03-1.70	3	C, LMB
Walter's Camp	0.92±0.59	0.49-1.60	3	C, CHC, LMB
Yuma Drain	0.71±0.17	0.48-0.86	4	C, LMB, TIL

(Continued)

Table 13. (Concluded)

Location	Mean±1 SD (ppm)	Range (ppm)	n	Species
Painted Rock Reservoir	0.77±0.27	0.42-0.86	4	C, CHC, LMB, TIL
Buckeye	0.70±0.17	0.58-0.82	2	C
Granite Reef Dam	0.49±0.08	0.37-0.54	4	C, LMB, YEB
San Carlos Reservoir	0.46±0.12	0.36-0.64	10	BGS, C, CHC, LMB

[a] Fish ≥2 ppm selenium whole body wet weight may have reproductive problems (Baumann and May 1984).

Table 14. Lower Colorado River selenium data for carp, double-crested cormorant (*Phalacrocorax auritus*), Yuma clapper rail, and holly-leaved water nymph (*Najas marina*). All mean values are from three individual specimens, except for Yuma clapper rail. Data from Radtke et al. (1988).

	Mean ± SD ppm wet whole body weight selenium			
Site	Carp	Double-crested cormorant	Yuma clapper rail[a]	Holly-leaved water nymph
Imperial Reservoir	2.5±0.9[b]	1.5±0.3	1.3±0.3 (7.2[b])	0.18±0.03
Draper Lake	1.4±0.1	---	---	0.05±0.0
Palo Verde Main Drain	0.8±0.1	1.6±0.5[c]	---	---
Palo Verde Oxbow Lake	2.9±1.2[b]	---	---	0.10±0.03
Palo Verde Diversion Dam	0.7±0.1	---	---	0.08±0.04
Headgate Rock Dam	1.1±0.0	---	---	0.13±0.03
Bill Williams Delta	1.2±0.1	---	---	0.07±0.01
Topock	1.4±0.2	---	---	0.05±0.02
Topock Marsh	1.6±0.4	1.5±0.3	---	0.06±0.02
Davis Dam	1.5±0.1	---	---	0.08±0.06

[a] First value based on two carcasses. Second value from one liver. Samples taken at Mittry Lake.
[b] Levels considered high enough to cause reproductive problems in fish (Baumann and May 1984) and in birds (see Radtke et al. 1988).
[c] *Sample from nearby Cibola Lake.*

Some pesticides such as DDT, herbicides, and their long-term breakdown products, such as DDE and DDD, as well as heavy metals are being detected in very high concentrations, especially along the lower Gila River, in both aquatic and terrestrial animal tissues (Kepner 1986; Radtke et al. 1988). Findings from these studies suggest that there may be serious persistent problems associated with the influence of mining, fossil fuel combustion, and agricultural chemicals within the entire Colorado River watershed.

3.3 FLOODPLAIN AND TERRACE SOILS AND SALINITY

Tremendous variation exists in the distribution of soils and associated salinities along the lower Colorado River. Extensive soil mapping inventories have been completed for areas under cultivation, but few easily discernible patterns exist. Surface soils are poor predictors of subsurface vertical and horizontal variation in type and salinity. Also, surface vegetation can be very misleading in identifying underlying soil and salinity characteristics, especially within mature and decadent stands of broadleaf and mesquite trees.

Extensive sampling within sites, however, reveals some trends for subsurface soil and salinity characteristics on a vertical axis. A simple classification of soils, based on soil texture, is presently being used to inventory soils of the lower Colorado River (Anderson, unpubl. data). Pure clay and pure sand are at the two extremes of this classification, with various combinations of clay, sand, and silt as intermediates. Preliminary results indicate that soil types at 0.5 m (1.6 ft) depths tend to be similar to soil types at 1 and 1.5 m (3 and 5 ft) depths. Salinity (as measured by electroconductance) within each sample site also tends to be similar at various depths. Finally, soil type and salinity tend to be related, with higher electroconductance in finer-grained soil at each depth in each hole, but explain very little of the total variance associated with spatial distribution (Anderson 1986; Anderson and Ohmart 1986b, unpubl. data).

Pure clay soils tend to have high salinity and poor drainage. Sandy soils, in contrast, are often low in salinity and well drained but do not hold nutrients very well. Intermediate soil types have intermediate salinity values and draining ability. Other factors that may influence the relative salinity of soil types include distance from delta and intensity of irrigation of cultivated areas. Salinities tend to be lowest farthest from the delta and where intense irrigation leaches salts out of the soil. Further work is needed to better delineate these trends (Anderson 1986; Anderson and Ohmart 1986b, unpubl. data).

Second-terrace surface soils tend to be sandy and gravelly, with loam and clay becoming more prominent closest to the river channel. Similarly, soils at the upper reach of the system tend to be more sandy and gravelly, with loam and clay becoming more frequent in lower reaches. When floods occur, however, sandy soils are carried much farther down the river than during normal flows. Modern-day manipulations (e.g., dredging) of the river channel also influence surface soils by forming extensive linear dredge spoils adjacent to the river channel. Dredge-spoil soils are often, but not always, very sandy to the water table.

CHAPTER 4. AGRICULTURAL USES OF THE VALLEY

4.1 AGRICULTURAL PRODUCTION

Agricultural interests are the most important influence over water resource development and allocation on the lower Colorado River. Consequently, agricultural development has had both direct (clearing riparian habitat) and indirect impacts (water development) on biotic community changes. Prior to 1980, over 90% of all water was used for irrigation of agricultural crops. Presently, the overall use of irrigation water is on both a proportional and absolute decline. Projections are that only 68% of all water resources will be used for irrigation by 2020 (Lower Colorado River Comprehensive Framework Study 1971). Increases in other water uses (including municipal, industrial, electric power generation, fish and wildlife, and recreation) account for the rest of the water allocation.

Productive agricultural land occupies about three-quarters of the lower Colorado River floodplain (Table 15) (U.S. Bureau of Reclamation 1986). Arable land is developed mostly in the Mohave, Parker, Palo Verde, Imperial, and Yuma Valleys. Current agricultural development is primarily on soils that once supported extensive honey mesquite stands. These stands continue to be cleared for agriculture, although the process has temporarily slowed because of low crop prices.

The major problem faced by early desert farmers was obtaining and holding adequate water to grow crops. With the development of water projects on the lower Colorado River, water became inexpensive and plentiful and an extensive agricultural industry was created. In addition, the closure of Hoover Dam in 1935 ensured protection of croplands from annual inundation. Agribusiness is still an important regional industry, although its overall influence is declining with increasing industrialization and urbanization of the entire basin.

In 1965, over half of all agricultural lands were entirely dependent on groundwater, with an additional one-third dependent on both groundwater pumpage and surface water irrigation. Average annual irrigation withdrawal rates of over 7,300 m^3/0.4 ha (6 acre-ft/acre) are common and in some areas withdrawals >12,000 m^3/0.4 ha (>10 acre-ft/acre) are required (Lower Colorado River Comprehensive Framework Study 1971). These high withdrawal rates result from the need to leach salts from the arable soil. As groundwater pumping continues and as drawdown exceeds recharge of the aquifers, greater dependency on surface water will be necessary to maintain present agricultural production.

Four major crops on the Colorado River Indian Reservation and nine major crops on the Palo Verde Irrigation District account for 95% of the total annual harvest, respectively (Table 16). Cotton, alfalfa, and grain crops (especially wheat, but also corn, barley, and milo) are the most important crops. Citrus orchards, melons, and vegetable truck

Table 15. Major agricultural areas on or near the lower Colorado River. Areas adjacent to the lower Colorado River are either supplied directly with Colorado River water or have irrigation return flow entering the Colorado River. Data from U.S. Bureau of Reclamation (1986).

Agricultural project	Irrigable hectares	Percent ha irrigated	Total gross crop dollar value	Dollar value per irrigated hectares
COLORADO RIVER FLOODPLAIN				
Mohave Valley	6,653	23	1,361,743	890.03
Colorado River Indian Reservation[a]	30,614	88	52,182,542	1,924.70
Palo Verde	49,850	95	Not avail.	Not avail.
Cibola	1,504	73	1,718,237	1,563.46
Yuma - Mesa	8,000	85	13,433,028	1,975.45
Yuma Reservation - Bard unit	2,848	89	22,318,414	8,804.11
Yuma Reservation - Indian unit	3,022	67	8,288,327	4,093.00
Yuma Valley	21,366	86	124,759,249	6,789.99
Yuma Auxiliary	1,362	74	1,130,573	1,121.60
Subtotal	125,803	86	225,010,280	2,868.38[b]
AREAS ASSOCIATED WITH COLORADO RIVER VALLEY				
Coachella Valley	31,412	75	235,804,672	9,881.36
Imperial Valley	207,824	88	488,980,104	2,631.37
North Gila Valley	2,492	93	27,442,324	11,700.76
South Gila Valley	4,240	91	33,026,114	8,448.93
Wellton-Mohawk	25,780	92	59,175,383	2,470.22
Subtotal	271,748	87	844,428,597	3,554.84
TOTAL	397,551	87	1,070,669,449	3,059.06[b]

[a]Data from 1983.
[b]Value calculated without Palo Verde irrigated hectares as total gross crop value was not available.

crops (primarily lettuce) are also important in the region.

The two most widespread crops are alfalfa and cotton, but these have little direct food value (Table 16). Wheat is the only crop that serves as an important human food source. Lettuce is the crop with the highest economic yield per hectare ($12,187.50 at Colorado River Indian Reservation), followed by melons (including cantaloupe, honeydew, and watermelon). Orchards also offer high economic yield but are restricted to the southernmost agricultural areas (Yuma

Table 16. Crops grown on the Colorado River Indian Reservation in 1983 and Palo Verde Irrigation District in 1986. Dollar value data are given for Colorado Indian Reservation crops. Data from U.S. Bureau of Reclamation (1986).

	Colorado River Indian Reservation			Palo Verde Irrigation District	
Type/crop	Area (ha)	Percent of total area	Dollar value/ha	Area (ha)	Percent of total area
Alfalfa	11,401	42	1,559.98	15,286	32
Cotton	10,836	40	1,750.06	6,648	14
Grain					
Barley	125		965.95	--	
Corn	--		--	1,909	
Milo	92		550.00	514	
Oats	12		450.00	--	
Rye	--		--	5	
Sesame	--		--	207	
Wheat	2,540		975.00	7,909	
Subtotal	1,769	10	958.20	10,544	22
Grasses					
Bermuda	206		800.00	563	
Sudan	220		563.52	193	
Subtotal	426	2	679.14	756	2
Melons					
Cantaloupe	320		7,560.00	2,008	
Crenshaw	--		--	55	
Honeydew	460		4,062.50	717	
Mixed	--		--	114	
Watermelon	75		4,488.00	341	
Subtotal	855	3	5,408.83	3,235	7
Orchards					
Citrus	--		--	725	
Other	--		--	6	
Subtotal	--	--	--	731	1
Pasture	114	<1	250.88	4,744	10
Vegetables					
Asparagus	--		--	102	

(Continued)

Table 16. (Concluded)

	Colorado River Indian Reservation			Palo Verde Irrigation District	
Type/crop	Area (ha)	Percent of total area	Dollar value/ha	Area (ha)	Percent of total area
Beans	24		1,720.83	--	
Broccoli	--		--	84	
Cabbage	--		--	22	
Cauliflower	--		--	110	
Lettuce	614		12,187.50	4,636	
Onions	16		6,150.00	359	
Squash	29		3,227.59	52	
Tomatoes	--		--	147	
Subtotal	683	3	11,297.84	5,512	12
TOTAL	27,084	100	1,926.69	47,456	100

Reservation-Bard Unit, Yuma Valley, Coachella Valley, and Gila Valley). The best crops for wildlife are grain crops, which are both moderately low in total area in cultivation (10% at Colorado River Indian Reservation and 22% at Palo Verde Irrigation District) and in economic value per hectare ($958 at Colorado River Indian Reservation).

4.2 AGRICULTURAL FEATURES AND PRACTICES AND USE BY WILDLIFE

Agricultural development and associated practices have had tremendous impacts on the biotic communities along the lower Colorado River. Much of the original flora and fauna have been affected negatively. Exotic plants and animals have increased, along with some native species. In general, the actual community dynamics of agricultural areas are poorly known. However, there have been extensive studies on the use of agricultural habitat by terrestrial vertebrate fauna, and some aquatic studies on canal systems (Minckley 1979; Anderson and Ohmart 1982a).

The most important agricultural practice is irrigation. The three main irrigation techniques are flood, sprinkle, and drip. Irrigation is necessary to water crops, but it is also important in leaching soils of undesirable solids (mostly salts). Recycling and reuse of irrigation return flow and percolating water result in very high concentrations of dissolved salts in the lower Colorado River.

Flood-irrigated fields flush invertebrates and fallen seeds to the surface and provide easy access to these food sources for vertebrate consumers. Irrigated areas also provide breeding sites for several species of toads (Anderson and Ohmart

1982a; Ohmart et al. 1985). Sprinkle and drip techniques have little influence on wildlife, but use irrigation water more efficiently.

An extensive network of canals has been developed to distribute water throughout the river valley as well as to transport water to urban areas in Arizona and California. Relative to wildlife use there are two major canal types--concrete-lined and unlined. The proportion of concrete-lined canals varies extensively among major agricultural areas. Of the total distance of canals, 54% are concrete-lined at Colorado River Indian Reservation on the high end of the scale, while less than 1% of canals are concrete-lined in the Palo Verde Irrigation District. Concrete-lined canals lose less water through seepage and support little vegetation, while unlined canals necessitate periodic dredging to remove vegetation and soil accumulations. In the lower Colorado River Valley canals provide standing water in an otherwise waterless area.

Unlined canals harbor well-developed aquatic communities. These can be important habitats for a number of marsh-nesting birds, muskrats (Ondatra zibethicus), beavers (Castor canadensis), and several species of reptiles and amphibians (Anderson and Ohmart 1982a). The ichthyofauna in canals consists exclusively of exotic species. Although the canal network is extensive, there is little information on aquatic community composition and species interactions. Concrete-lined canals may provide some habitat for fish and diving ducks; however, these habitats are biologically depauperate in both biomass and species richness, when compared with unlined canals.

Field margins also provide varying habitats for wildlife, depending on whether these areas are devoid of vegetation or allowed to remain weedy. The current rationale among farmers is that weed control reduces potential pest species (i.e., insects, rodents, and weed seeds). Margins devoid of weeds are often inhabited by burrowing animals such as burrowing owl (Athene cunicularia) and round-tailed ground squirrel (Spermophilus tereticaudus). Weedy margins contain abundant weed seeds, insects, and cover. These areas are among the most important habitats available in agricultural areas for many granivorous and insectivorous birds, nocturnal rodents, and several species of reptiles (especially western whiptail [Cnemidophorus tigris]).

Orchards are the only agricultural habitats with vertical vegetation structure and, therefore, are potentially important to birds. The three major orchard types in the lower Colorado River Valley are date palm, citrus, and grape. Orchards, especially citrus, are important to white-winged (Zenaida asiatica) and mourning (Zenaida macroura) doves for nesting habitat, but, otherwise, are not heavily used by other breeding birds (Figure 29). In winter, visiting insectivorous birds are common in these orchards. Granivores are common year-round in orchards, especially grape orchards. Most resident insectivorous birds use orchards only secondarily.

Other important wildlife habitat features are found in agricultural areas, but they only make up a small fraction of the total area. Feedlots are important to a large numbers of birds, especially wintering granivores. Transmission powerlines provide important perches for raptors and aerial-foraging insectivores. Inhabited areas often provide a diversity of food resources and concentrate many bird species into relatively small areas.

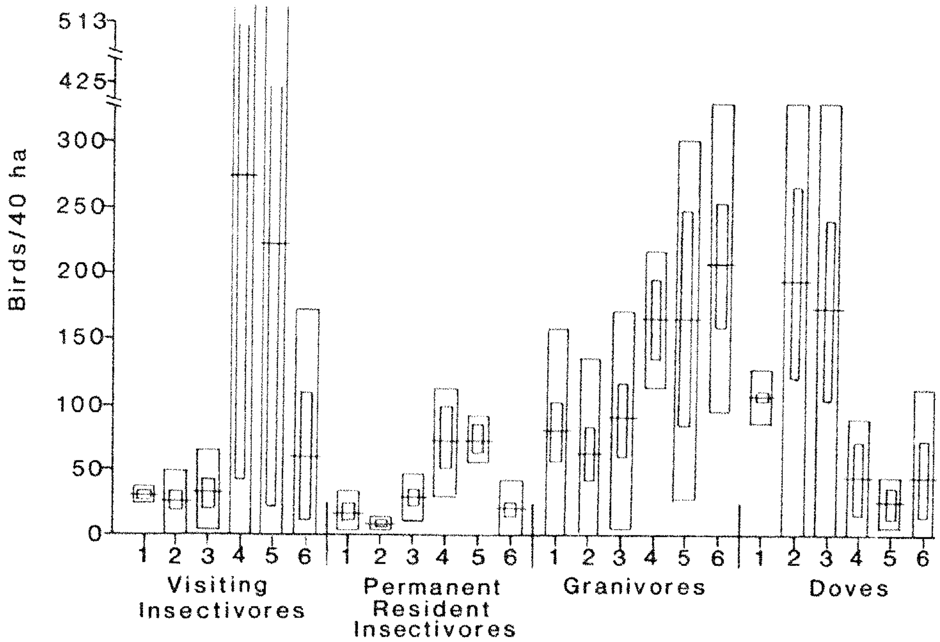

Figure 29. Average densities of birds in different orchard types. Horizontal bar is average; large rectangle represents one standard deviation; small rectangle represents two standard errors of the mean. 1 = young citrus; 2 = moderately young citrus; 3 = mature citrus; 4 = date palm and citrus; 5 = date palm; and 6 = grape. From Anderson and Ohmart (1982a).

One practice that may affect faunal use of agricultural areas is the continued widespread use of insecticides and herbicides whose use is likely to continue. Genetic resistance is countered by using greater concentrations and by the development of new insecticides.

Anderson and Ohmart (1982a) reported on patterns found in insecticide and herbicide use among the major agricultural areas in the valley between 1977 and 1980 (Tables 17 and 18). They found an association by area between reduced avian populations and increased use of insecticides (Figure 30). Also, as the amount of insecticide use increased from 1977 to 1980, bird population numbers declined. Canals, weedy margins, and inhabited areas were the best avian habitats and these were usually removed from insecticide target areas. However, bird use of these noncropland areas demonstrated even a stronger negative relationship with insecticide use than that for overall agricultural bird use. Herbicide use was not associated with declines in birds (Anderson and Ohmart 1982a). These findings are purely correlative and merely suggest (i.e., does not prove) cause and effect. Controlled census data are needed from fields treated with insecticides versus those not

Table 17. Insecticide and herbicide application on various crop types. Data from the California Agricultural Commissioners Office, Pest and Weed Control Report, 1979. Adapted from Anderson and Ohmart (1982a).

		Insecticides		Herbicides, fungicides, defoliants	
Crop	Ha	l/0.4 ha	kg/0.4 ha	l/0.4 ha	kg/0.4 ha
Alfalfa	32,169	0.30	0.30	0.19	0.34
Cotton	92,328	0.76	0.39	0.30	0.02
Truck	60,095	0.64	1.36	1.89	0.14
Grain	7,154	0.08	0.58	0.53	0.16

Table 18. Insecticides and herbicides applied to the equivalent of 360 ha (900 acres) of cropland in four agricultural areas. The corresponding avian densities are the number per 40 ha (100 acres) for all crop types and other agricultural features such as weedy margins, and canals. CRIR = Colorado River Indian Reservation, WM = Wellton-Mohawk, IC = Imperial-Coachella, and MO = Mohave. From Anderson and Ohmart (1982a).

		Hectares			Insecticide		Herbicide		Totals		Mean bird density per 40 ha
Area	Year	Cotton	Alfalfa	Other	l	kg	l	kg	l	kg	
CRIR	1977	134	147	80	488	513	208	157	696	670	220
	1978	117	158	87	466	530	238	169	704	699	184
	1979	174	110	76	541	513	220	126	761	639	167
	1980	184	110	66	508	489	223	122	730	611	142
WM	1978	116	122	122	507	622	201	150	708	772	198
	1979	113	169	78	466	505	201	175	667	680	224
	1980	104	123	132	503	646	197	156	700	802	172
IC	1978	56	10	294	587	1060	185	111	772	1171	169
	1979	67	10	283	587	1033	189	107	776	1140	135
	1980	59	6	294	587	1060	189	108	776	1168	136
MO	1978	65	0	295	594	1065	189	105	783	1270	54
	1979	202	0	158	632	734	231	66	863	800	56
	1980	246	0	114	644	630	246	54	890	684	57

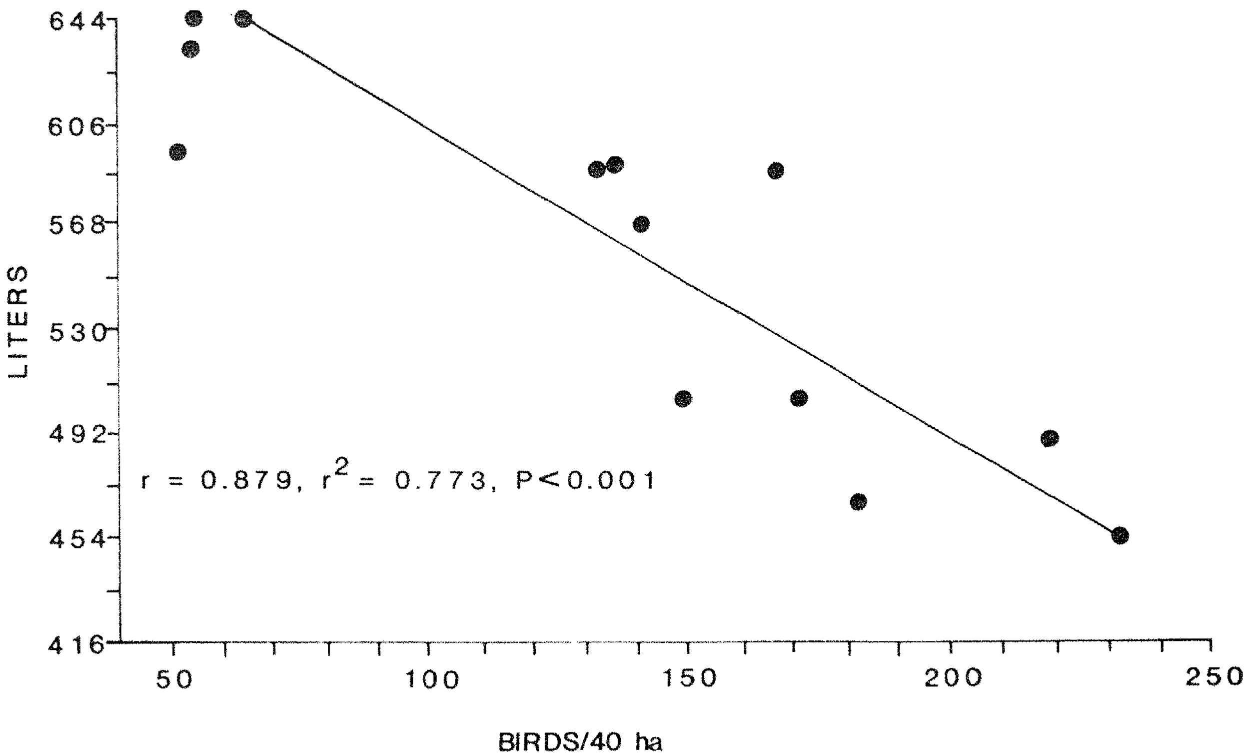

Figure 30. Association between pesticide application and avian densities. From Anderson and Ohmart (1982a).

treated in order to assess actual cause and effect. Presently, the U.S. Fish and Wildlife Service is assessing insecticide residuals in representative vertebrates in major agricultural areas in Arizona, including the lower Colorado River Valley (Kepner 1986; Radtke et al. 1988).

Toxic spills are infrequently documented, but when they do occur they have devastating results. Minckley (1979) reported on the immediate effects of a highly toxic insecticide siphoned from the tanks of an applicator aircraft into the main intake canal for the Yuma Valley irrigation network in 1974. A complete kill of fishes and other aquatic organisms was observed within two days. A more recent (1987) spill near Parker also had severe negative effects.

Agriculture presently dominates water and land use in the lower Colorado River Valley. Some species benefit from agriculture, but many others do not. A mosaic of native habitats and agricultural crops, complete with weedy field margins and unlined canals, would result in a balance between native and introduced species.

CHAPTER 5. OTHER HUMAN USES OF THE VALLEY

5.1 WATER-RELATED RECREATION

Water recreation is the second largest use of lower Colorado River water, even though it is nonconsumptive. About 75% of the available water area is presently used for water-based recreation. Projected annual recreation needs will increase 500% by the year 2020, resulting in extensive crowding throughout the region (Lower Colorado River Comprehensive Framework Study 1971). Accommodation of recreationists is a major concern of government planners and managers.

Recreation on the lower Colorado River occurs primarily in summer and is based around reservoirs and along channelized stretches. The Colorado River attracts recreationists from throughout southern California, Nevada, and Arizona and provides an important economic source to lower Colorado River communities. The summer flood of 1983 necessitated closure of the river, except at Lakes Mohave and Havasu, causing economic hardship to local businesses and resort owners.

The greatest direct impacts on the biota from water recreational activities are on bank and shoreline habitats and waterbirds (Figure 31). Riparian vegetation is crushed by off-road vehicles or is disturbed by wave action from boats. Heavy boat traffic (wave action) disrupts fish spawning in coves (especially striped [Morone saxatalis] and largemouth bass [Micropterus salmoides]) and waterbird breeding during summer in some years (principally, western [Aechmophorus occidentalis] and Clark's [A. clarkii] grebes and Yuma clapper rail). Winter boat traffic, although not as heavy as in summer, can also disturb waterfowl. Several coves on the Chemehuevi Indian Reservation have been closed to water skiing on the California side of Lake Havasu to protect largemouth bass spawning areas.

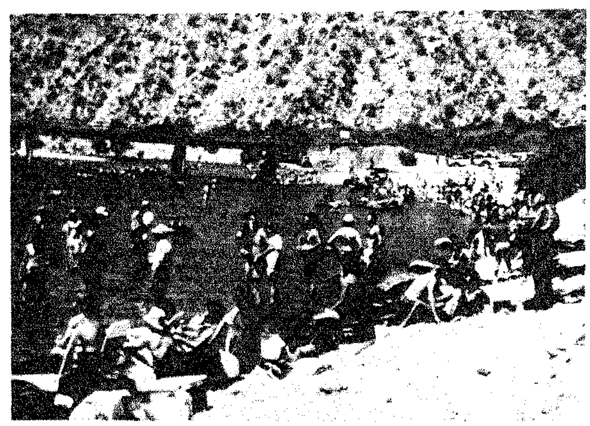

Figure 31. Recreational uses along riparian corridors include concentrations of people operating or using rafts, boats, and off-road vehicles. Photo is from the Salt River upstream from Phoenix, AZ, by R.E. Tomlinson.

5.2 RECREATIONAL AND TRAILER PARKS

Increasing numbers of tourists (principally in relation to water-based recreation), seasonal residents (principally during winter), and retirees have led to an increasing demand for recreational vehicle and mobile home parks. Localized impacts on vegetation and wildlife from increased clearing, vehicular abuse, and predatory feral animals (dogs, cats) can be dramatic.

Tourism, related to the gambling industry in the Laughlin-Bullhead City area, has resulted in a recent expansion of real estate development and water-based recreation in that area. Proposed development surrounding Laughlin Lagoon, the largest of the backwater lagoons created by training dikes, has sparked tremendous concern over the loss of aquatic resources in the area (Burrell 1987). During spring and early summer large numbers of striped bass migrate into the area from Lake Havasu to spawn. Presently, striped bass over 9 kg (20 lbs) are rare, and this fishery appears to be in trouble. The decline of the striped bass fishery may be due to a number of reasons (including declining trophic stability in the system), but the reduction of an important spawning area will further strain the population. In addition, a few razorback suckers, a species of special concern, are found in the area, although their breeding status is not known. Finally, attempts to control blackflies (Simuliidae) in response to projected negative effects on local tourism may be causing declines in game fish, such as rainbow trout (Salmo gairdneri), which feed primarily on blackfly larvae (Burrell 1987).

Expanding real estate development in and around Lake Havasu City has also had impacts on biotic resources as well as on resource agencies. One such proposed development, "Jop's Landing," was well publicized and resulted in a realignment of Havasu National Wildlife Refuge's boundary to allow access to the lake in 1983. This realignment was objected to by conservation groups and the Arizona Department of Game and Fish as the development could seriously impact nearby Yuma clapper rail habitat, an endangered species. This case, however, demonstrated the power developers can have over resource agencies in reaching their goals, despite possible impacts on the associated biotic communities.

5.3 IMPORTANCE OF RECREATION LANDS

The largest tracts of land that can still be managed as wildlife habitat are under county, State, or Federal Government control. These areas have been set aside for recreation, as well as for wildlife, and support a wide variety of uses. Most of these outdoor activities would seem compatible with (and even enhanced by) the presence of natural greenery.

Many of these "parks" are little more than paved parking lots for fishermen, boaters, and recreational vehicles. Nonnative tree species, particularly eucalyptus (Eucalyptus spp.) and fruitless mulberry (Morus spp.), are often used in the development of recreational parkland and provide little habitat for native birds. Federal, State, and county park officials have the potential to restore disturbed areas with native species such as cottonwood, willow, mesquite, and various native shrubs. Restoration of these species would be beneficial to wildlife and also would provide more aesthetic conditions for recreation (birdwatching) and much needed shade for parks.

In many parts of the lower Colorado River Valley, tall vegetation is restricted to areas surrounding human habitations. Therefore, landowners and private developers can greatly impact the future of these areas for wildlife. Most landowners are unaware of the value of these habitats to wildlife. The actions of a few enlightened landowners emphasize how important residential plantings are to a variety of wildlife species.

It is clear that a large array of wildlife species will live and breed in close proximity to humans if suitable vegetation is provided. With careful planning, stable populations of certain sensitive species can probably be maintained or reestablished in areas where only a little adjacent native vegetation remains. Other species may never adapt to these artificial environments and such areas can never fully replace natural riparian communities. In addition, the possible negative effects on sensitive species of increasing populations of pest species (i.e., feral cats and dogs, rats, cowbirds, and starlings) on native wildlife requires further study.

5.4 FISHING AND HUNTING RESOURCES

Before the closure of Hoover Dam, fishing primarily was for Colorado squawfish (Ptychocheilus lucius) and razorback sucker. Presently, all sports fishing is for introduced species. About 88,000 ha (220,000 acres) of warm-water habitat supporting sports fisheries now occur on the lower Colorado River. Fish populations, from stocking and natural propagation, presently support 3 million man-days annually. Sport fish populations on the lower Colorado River and its many impoundments potentially satisfy only a portion of projected demand. Competition for available surface water from other uses that are incompatible with fishing will not allow complete demand satisfaction (Lower Colorado River Comprehensive Framework Study 1971). Specifically, speedboating and shoreline development will reduce fishing quality and quantity.

At least 80% of the fishermen on the Colorado River south of Davis Dam are nonresident, and most are from the Los Angeles area. The large number of nonresident fishermen and a sparse resident population results in a high per capita use rate. The ratio of resident-to-nonresident fishermen and the per capita use rate is expected to increase through the year 2020.

Hunting on the lower Colorado River, particularly dove and goose hunting, also attracts a large number of nonresidents. A total of 750,000 man-days annually are spent hunting in the lower Colorado River area (Lower Colorado River Comprehensive Framework Study 1971). About half of this total is spent hunting big game (mule deer [Odocoileus hemonius]), mostly in the desert and mountains along the river. The remainder of effort is spent hunting small game almost entirely on and adjacent to the river.

Ideal conditions for many game species were initially provided by early agricultural practices using dense hedgerows around small, isolated agricultural tracts; inefficient grain harvesting practices; and the predominance of grain crops. These practices provided abundant food, escape and nesting cover, and edge effects. Today, extensive farm tracts, clean farming practices, and shifts to crops such as cotton, alfalfa, and lettuce have caused declines in the amount of these wildlife habitats. In addition, river management with dredged and riprapped channels, desiccated oxbow lakes, and extensive nonconsumptive recreational activities has reduced the quality of aquatic habitat for waterfowl species.

5.5 URBAN DEVELOPMENT

Suburban and urban developments are small along the lower Colorado

River, with Yuma (population 86,000) being the largest city. Urban developments along the river are associated with uses such as agriculture (Blythe), tourism (Lake Havasu City), and the military (Yuma). Urban impacts on the biota of the lower Colorado River are minimal compared with impacts from both agriculture and tourism.

Water for municipal and industrial needs presently amounts to about 5% of the total water resources available. By 2020, about 15% will be required to support municipal and industrial demands (Lower Colorado River Comprehensive Framework Study 1971). Of the water allocated for municipal and industrial development along the lower Colorado River, about 90% is diverted to Las Vegas and Clark County, NV, before reaching Davis Dam.

Domestic and commercial uses demand most of this water. Domestic uses are concentrated around the towns and cities, with Yuma having the largest demand. Commercial demands are primarily from recreational and tourist parks. The Federal Government (primarily the military in the Yuma area) also uses significant amounts of water. Yuma presently uses river water diverted from Imperial Dam. Water quality remains a problem. Agricultural use of Colorado River water upstream has served to increase concentrations of dissolved solids (salts) in Yuma's supply.

CHAPTER 6. RECENT TRENDS IN RIPARIAN HABITAT CHANGES ON THE LOWER COLORADO RIVER

Dramatic changes have occurred in the riparian habitat along the lower Colorado River as a result of agricultural conversion since 1938. This chapter quantifies these changes in two ways. The vast majority of riparian habitat conversion to agriculture occurred before 1976, and these changes are described simply in terms of changing areal extent of plant communities and agricultural cropland. The first section discusses these plant community and agricultural changes from 1938 to the present in the Parker II Division, which were typical of changes valley wide. The second section discusses changes in riparian vegetation among community/structure types from 1976 to 1986, as described by Anderson and Ohmart (1986c). The Anderson and Ohmart (1986c) procedures for defining community/structure types is described in more detail in section 6.2 and Appendix A. The third and final section covers changes in emergent wetlands from 1976 to 1986.

6.1 PARKER II HABITAT CHANGES

The Parker II Division extends from the town of Parker south 71 river km (44 river mi) to the Palo Verde Diversion Dam and includes the entire Colorado River Indian Reservation. This division encompasses 21,504 ha (53,760 acres), much of which has been converted to agriculture. Agricultural development on Indian reservations was accelerated about two decades after development on non-Indian lands. The increased rate of clearing after 1960 was the result of a bill passed by Congress in 1955, which allowed long-term leasing on Indian lands (Fradkin 1981). Indians could retain ownership of lands, but they also could lease them well below market value; in effect, Indian tribes could maintain an income while opening their lands to non-Indian operations.

In an attempt to document rates of change in habitat, Mizoue (1984) analyzed data from twenty-eight, 4.5-km (2.8-mi) transects, each running west to east across the division. Data on habitat change were collected from aerial photographs taken in 1938, 1960, 1976, and 1983. Rates of change were compared between two periods, 1938-1960 and 1960-1982. Since Mizoue's (1984) study was conducted another set of vegetation maps has been produced; these data are also included here for discussion.

The predominant plant community in the first terrace (bottom) was cottonwood-willow in 1938. Honey mesquite was the dominant plant community on the second terrace. These two plant communities combined covered 74% of the entire Parker II Division (Figure 32, Table 19). Agricultural land only covered 0.3% in 1938. Saltcedar was present but only covered 1.6% of the division. Screwbean mesquite and arrowweed accounted for 0.6% and 5.6%, respectively; thus, these two native habitats were relatively unimportant in an areal context.

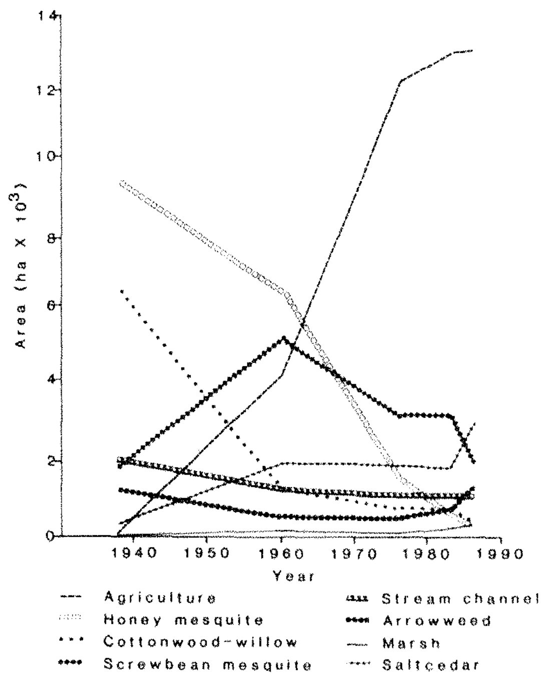

Figure 32. Change in plant communities in the Parker II Division from 1938-1986. Total ha = 21,504 (53,760 acres). Data from Mizoue (1984).

Twenty-two years later, in 1960, screwbean mesquite and saltcedar increased significantly in the first terrace to encompass 25% and 9% of the division. These increases were at the expense of the cottonwood-willow community which declined by 80% of its original area to cover only 6% of the division (Table 20). Agricultural land increased from 0.3% in 1938 to 20% of the division by 1960. This change was mostly at the expense of honey mesquite and arrowweed communities. Marsh communities increased slightly while the stream channel decreased slightly.

Although the changes from 1938 to 1960 were dramatic, the amount and rate of change between 1960 and 1976 were even more so. The rate of conversion to agriculture increased almost three times from 196 ha/yr (489 acres/yr) to 494 ha/yr (1,234 acres/yr). Again, this was mostly at the expense of honey mesquite which by 1976 covered only 8% of the division, with a conversion rate of 312 ha/yr (781 acres/yr). Changes in the first terrace were less dramatic but were still in the negative direction for cottonwood-willow, which by 1976 covered only 4% of the division. Much of the area covered by screwbean mesquite in 1960 was lost by 1976. Little change occurred in the areal extent of arrowweed, saltcedar, and marsh communities.

The conversion of honey mesquite to agriculture has continued, but at a slower pace, from 1976 to 1986. Presently, agriculture covers over 60% of the Parker II Division, while honey mesquite covers about 1%. The slower pace reflects as near a maximum development as possible of agriculture on the second terrace. The first terrace also has been converted almost completely from cottonwood-willow to saltcedar and screwbean mesquite communities. Since 1983, there was a switch in the relative ranking of screwbean mesquite and saltcedar, with saltcedar now the dominant riparian community.

Mizoue (1984) determined that rates of change between 1938 and 1960 were nonconstant and, therefore, could not predict changes that occurred from 1960-1982 (Table 21). Accelerated increases in agriculture conversion after 1960 were largely responsible for the lack of predictability. In addition, changes in the first terrace were also not predictable. Predicted vegetation change from 1960-1982 was able to closely parallel real changes; however, this does not necessarily support the use of this model for

Table 19. Proportion of total area of each plant community within each year in Parker II Division. Communities are CW = cottonwood-willow, HM = honey mesquite, AW = arrowweed, ST = stream channel, AG = agriculture, SM = screwbean mesquite, SC = saltcedar, and MA = marsh.

	Proportion of total area									
	All communities					Riparian communities				
Community	1938	1960	1976	1983	1986	1938	1960	1976	1983	1986
CW	30.5	6.0	3.7	3.2	1.9	30.5	7.5	8.5	8.4	4.8
HM	43.7	30.7	7.5	2.6	1.1	43.7	38.5	17.3	6.6	2.7
AW	5.7	2.6	2.3	3.3	5.9	5.7	3.2	5.4	8.4	15.3
ST	9.6	6.0	5.0	5.2	5.0	9.6	7.5	11.7	13.2	12.8
AG	0.3	20.3	57.0	60.6	61.1	--	--	--	--	--
SM	8.7	24.6	15.1	15.3	9.7	8.7	30.9	35.2	38.8	25.1
SC	1.6	9.0	8.9	8.7	14.1	1.6	11.3	20.6	22.1	36.2
MA	0.0	0.8	0.5	1.0	1.2	0.0	1.0	1.2	2.5	3.2
Total ha	----------21,504----------					21,440	17,139	9,240	8,470	8,357

Table 20. Percent and rate of change within plant communities among time periods in Parker II Division. Vegetation abbreviations the same as in Table 19.

	Percent change					Average number ha per year				
Community	1938-1960	1960-1976	1976-1983	1983-1986	Total	1938-1960	1960-1976	1976-1983	1983-1986	Total
CW	-80	-39	-10	-43	-94	-240	-32	-11	-102	-128
HM	-30	-76	-65	-59	-98	-127	-312	-149	-111	-191
AW	-54	-11	+43	+79	+0.1	-29	-4	+30	+188	+2
ST	-38	-16	+4	-5	-48	-88	-13	+6	-18	-21
AG	+6,657	+181	+6	+1	+20,276	+196	+495	+110	+38	+272
SM	+183	-39	+1	-36	+12	+156	-128	+5	-396	+5
SC	+462	+1	+2	+61	+779	+72	-2	-4	+383	+56
MA	+100	-35	+87	+27	+100	+8	-4	+14	+18	+6

Table 21. Results of Mizoue's (1984) 1938-1960 and 1960-1983 models to predict habitat changes in Parker II Division.

	Hectares of community			
Community type	Results of 1938-1960 model	Results of 1960-1983 model	Actual 1983	Actual 1986
Cottonwood-willow	792	720	708	401
Honey mesquite	4,622	570	561	229
Arrowweed	1,101	720	712	1,278
Stream channel	1,074	1,140	1,121	1,066
Agriculture	8,624	13,240	13,034	13,147
Screwbean mesquite	5,907	3,330	3,283	2,095
Saltcedar	2,753	1,910	1,876	3,025
Marsh	276	210	208	264

changes after 1982. The 1960-1982 model predicted that agriculture will continue to increase, while the areal extent of all other riparian communities will slowly decrease through time, except that saltcedar will decrease slowly at first, level off, and then finally begin to increase (Mizoue 1984). These later predictions are borne out in the 1986 results, but these changes were also probably accelerated by the 1983-1984 flooding.

Plant community changes within the first terrace, presently defined by the levees paralleling the river, are not directly influenced by human activity, as are the second terrace communities. Rather, the first terrace changes are mostly indirect, with changes in ecological succession processes, river flow levels, and salinity levels. Of special note was the rate of change among the three major first terrace communities: cottonwood-willow, screwbean mesquite, and saltcedar. The steepest decline in cottonwood-willow occurred between 1938 and 1960 and reflects the gradual death of trees, with little or no recruitment. During this same period, screwbean mesquite increased tremendously as did saltcedar. From 1960 to 1976, cottonwood-willow continued to decline, with virtually no recruitment, while screwbean mesquite also declined somewhat. Saltcedar remained constant during this period. The areal extent of screwbean mesquite and saltcedar leveled between 1976 and 1983, while cottonwood-willow continued to decline.

The flooding between 1938 and 1986 was thought to possibly provide for flushing of salts and establishment of germination beds for cottonwoods and willows, while decreasing the extent of saltcedar. Thus far in the Parker II Division the opposite has happened. Cottonwood-willow continues to decline, with no apparent reproduction, while saltcedar has replaced screwbean mesquite. All stands of screwbean mesquite and cottonwood-willow contain an understory dominated by saltcedar. The flooding in effect killed many screwbean mesquite and most of the remaining cottonwood-willow trees. The vigorously growing saltcedar was able to take over in these stands before any regeneration of native trees could occur. In addition, numerous fires and clearing operations within the levees in areas not flooded have also resulted in saltcedar dominance.

The habitat changes occurring in the Parker II Division are typical of those throughout the river system, with extensive agricultural development, including the Mohave, Palo Verde, Laguna, Yuma, and Limitrophe Divisions. Since 1976, most habitat changes are within riparian vegetation types between the levees and constitute both community and structure type changes. These changes are discussed in detail in the following section, which also quantifies the short-term flooding effects since 1983.

6.2 RIPARIAN HABITATS FROM 1976-1986

Riparian habitat changes from 1976 to 1986 are described using the procedure developed by Anderson and Ohmart (1986c). The Anderson and Ohmart (1986c) system allows for the quantification and easy identification of community/structure types in the field (see Appendix A for description and methods for this classification system and the National Wetlands Inventory classification). The number of structure types is based on the relative importance of the understory, midstory, and canopy. These are based on foliage measurements in each layer. Anderson and Ohmart (1986c) and Anderson et al. (1983) provided a detailed analysis of vegetation characteristics (tree counts, foliage density, foliage height diversity, and patchiness) for each type in each identified plant community (=association).

The concept of structure typing is not difficult to understand if an area is envisioned as going from bare soil to supporting a mature cottonwood forest (Appendix A). Type VI is the beginning community of regenerated vegetation. As the stand develops, it passes through types V, IV, and III until it becomes type I, which is the mature community. In type VI the vast majority of foliage is in the understory. Type I, at the other extreme, has well-developed understory, midstory, and canopy layers; such habitats also tend to be very high in foliage height diversity and patchiness (Anderson et al. 1983). As the stand continues to mature and a closed canopy develops, the understory tends to be shaded out and the stand becomes type II. As the mature cottonwood-willow trees die and the canopy opens, the midstory develops with newly regenerated cottonwood, willow, or other plant species (saltcedar and/or mesquite). Eventually, given no extrinsic factors (i.e., clearing, flooding, fire), the stand will undergo succession to a disclimax stand dominated by mesquite or other plant species. Presently, mesquite and saltcedar rarely develop beyond type III in the Southwest. Typically, the lower the structure type the more xeric, saline, or otherwise unfavorable the site is.

Net total area changes in riparian vegetation were not dramatic from 1976 to 1986, with only 200 ha (500 acres) being lost (Table 22). In interpreting these and other net changes in habitats it is important to realize that riparian habitats were being cleared for agriculture or lost by other means, while some abandoned agricultural areas were being naturally revegetated. Similarly, net losses in any particular habitat or set of habitats does not mean there are no new stands developing, but rather that

Table 22. Community/structure type (habitats) and total area among years on the lower Colorado River.

Community/structure type	Number of hectares		
	1976[a]	1983[b]	1986[c]
Cottonwood-willow			
I	155	0	0
II	38	65	90
III	188	237	201
IV	1,779	1,832	693
V	978	680	1,147
VI	216	376	171
Saltcedar			
I	43	132	124
II	76	40	4
III	135	170	4
IV	10,154	9,004	8,952
V	2,779	4,175	7,024
VI	1,164	2,023	1,906
Arrowweed			
VI	1,596	2,029	2,991
Honey mesquite			
III	734	491	436
IV	4,221	3,620	3,556
V	1,604	862	633
VI	0	14	8
Screwbean mesquite			
II	110	40	0
III	752	307	144
IV	5,558	4,827	3,130
V	1,846	2,095	2,827
VI	145	1,283	96
Saltcedar-honey mesquite mix			
III	71	82	11
IV	2,132	2,860	2,386
V	1,013	1,094	752
Total	37,487	38,338	37,286

[a]From Anderson and Ohmart (1976).
[b]From Anderson and Ohmart (1984c).
[c]From Younker and Andersen (1986).

there are more losses than gains during the stated time period. The opposite is true for net gains.

Two important habitats, cottonwood-willow (CW) I and screwbean mesquite (SM) II, have been lost entirely from the river system since 1976. These two community/structure types were very important habitats in 1976 to wildlife and structural diversity in vegetation. CW I made up 155 ha (388 acres), all in one stand in the Bill Williams Delta, and was lost to flooding from 1978-1981 (Hunter et al. 1987). SM II, consisting of 110 ha (275 acres) in 1976, was reduced to 40 ha (100 acres) in 1983, and was completely lost by 1986 due to clearing for agriculture. SM II occurred in one stand on the Colorado River Indian Reservation near the Wagon Wheel Resort and was an important nesting area for thousands of white-winged doves. CW I and SM II were critically important to a large number of rare and declining bird species, and the loss of these habitats has greatly reduced these populations (Hunter 1984). Finally, these habitats represented the highest development of structural diversity in vegetation for both cottonwood-willow and screwbean mesquite plant communities. Present trends indicate that these "climax" states will not be reached again anytime in the near future.

A number of habitats are rare and should be monitored. Among these habitats, CW II, CW III, honey mesquite (HM) III, SM II, and saltcedar-honey mesquite (SH) III are important habitats to wildlife and, again, are high in structural development. Saltcedar (SC) I, II, and III are all potentially threatened, and these habitats are the most important areas within this exotic plant community. Finally, very little regeneration (type VI) is occurring in cottonwood-willow, honey mesquite, screwbean mesquite, and saltcedar-honey mesquite plant communities. These trends necessitate a pessimistic view for the future recovery of native habitats.

Although there has been little net change in total riparian vegetation, there has been extensive change in the dominance of community and structure types. All native habitats, except arrowweed, and the higher saltcedar structure types have declined substantially from 1976 to 1986 (Table 23). Besides arrowweed, only the lower saltcedar structure types increased throughout the decade.

The overall trends in habitats on the lower Colorado River are two-fold. First, the higher structure types (I, II, and III) are on the decline in all plant communities, and there appears to be virtually no recruitment from lower structure types (IV, V, and VI). Second, exotic saltcedar continues to increase largely at the expense of cottonwood-willow, screwbean mesquite, and some honey mesquite-dominated stands with saltcedar as a understory component. Speculation that the 1983-1984 flooding would increase cottonwood-willow recruitment is not supported by these data, at least in the short term, even though there are some areas experiencing recruitment (primarily from Yuma south). In fact, the flooding of 1983 has apparently accelerated the deterioration of native habitats in favor of saltcedar types IV, V, and VI. Saltcedar rarely develops above type IV on the lower Colorado River because of periodic fires and this tree's aggressive response to frequent disturbance.

The Importance of Patch Size

The size of a stand or a patch of habitat is important in predicting use by wildlife or the integrity of the

Table 23. Changes in riparian vegetation structure types among years on the lower Colorado River. CW = cottonwood-willow, SM = screwbean mesquite, HM = honey mesquite, SC = saltcedar, SH = saltcedar-honey mesquite mix, AW = arrowweed. Structure types are as described by Anderson et al. (1983) with types I, II, and III having proportionately more foliage in the upper layers.

	Hectares			Percent changes between years		Overall change
Habitat types	1976[a]	1983[b]	1986[c]	1976-1983	1983-1986	1976-1986
CW I, II, III	380	302	291	-21	-4	-24
CW IV, V, IV	2,974	2,888	2,011	-3	-30	-32
SM II, III	863	347	144	-60	-58	-83
SM IV, V, VI	7,549	8,205	6,053	+9	-26	-20
HM III	734	491	436	-33	-11	-41
HM IV, V, VI	5,825	4,497	4,197	-23	-7	-28
SC I, II, III	254	342	132	+35	-61	-48
SC IV, V, VI	14,098	15,202	17,883	+8	+18	+27
SH III, IV, VI	3,216	4,036	3,149	+27	-23	-2
AW VI	1,596	2,029	2,991	-27	+47	+87

[a]Anderson and Ohmart (1976).
[b]Anderson and Ohmart (1984c).
[c]Younker and Andersen (1986).

stand itself. The larger the stand the healthier it is in an ecological diversity context, especially when it is greater than 40 ha (100 acres). Thus, a crucial question concerning the rare but important habitats is whether they occur in relatively large stands that support associated wildlife species of concern and can withstand local disturbances.

Data from 1983 type maps (Anderson and Ohmart 1984c, prepared by D.E. Busch, unpubl.) were used to assess patch size among habitats (Table 24). Cottonwood-willow habitats, generally among the habitats lowest in total area, are very low in mean patch size compared with other plant communities. This suggests that most cottonwood-willow stands are widely scattered among other plant communities and are of marginal value from the standpoint of use by wildlife species of special concern.

Spearman rank correlation coefficients (r_s) were calculated to determine associations between total area, structure, number of patches, and mean patch size of each habitat (Table 25). This was done for all riparian habitats and for riparian habitats between the levees (CW, SM, and SC). Total area was significantly associated with structure type, number of patches, and mean patch sizes among habitats: the larger the total size of a habitat, the lower the structure type ($P \leq 0.025$), the larger the number of patches ($P \leq 0.001$), and the larger the mean patch size ($P \leq 0.025$). Structure

Table 24. Patch size and divisions which were present for habitats in 1983. Data summarized by Busch (U.S. Bureau of Reclamation, unpubl.).

Community/ structure type	Number of patches	Patch size (ha) Mean size of patch	2 standard errors	Range of size	Divisions present in[a]
SC I	5	26.4	8.2	3.4-49.1	YU, MO
SC II	1	40.5	--	---	PV
SC III	18	9.4	1.3	1.0-8.0	Mo, TK, HA, CI
SC IV	269	33.5	2.6	0.3-1,326.5	LI, YU, LA, IM, CI, PV, PA, HA, TK, MO
SC V	93	44.9	1.6	0.3-430.6	MO, TK, HA, PA, PV, CI, IM, LA, YU, LI
SC VI	49	41.3	2.2	1.7-243.5	LI, YU, LA, IM, CI, PV, PA, HA, MO
CW I	0	0.0	0.0	0.0	-------
CW II	5	13.0	7.4	1.4-45.5	HA, PA, PV, CI
CW III	19	12.5	1.2	3.2-47.4	YU, LA, IM, CI, PV, HA, MO
CW IV	68	26.5	1.2	0.7-226.7	MO, TK, HA, PA, PV, CI, IM, LA, YU, LI
CW V	27	25.4	2.4	1.5-119.0	LI, YU, LA, IM, CI, PV, PA, HA, MO
CW VI	15	25.0	5.6	1.6-170.2	LI, YU, CI, PV, MO
SM II	1	39.6	--	---	PA
SM III	19	25.0	3.4	1.1-142.7	YU, LA, PA, MO
SM IV	133	37.1	1.0	0.7-535.2	MO, TK, HA, PA, PV, CI, IM, LA, YU, LI
SM V	68	30.8	1.2	0.4-188.6	LI, YU, LA, CI, PV, PA, MO
SM VI	3	51.3	15.2	5.0-287.9	MO, PA, PV, CI, YU

(Continued)

Table 24. (Concluded)

Community/ structure type	Number of patches	Patch size (ha)			Divisions present in[a]
		Mean size of patch	2 standard errors	Range of size	
HM III	7	70.2	15.9	4.9-185.3	PV, MO
HM IV	35	101.9	17.0	0.3-1,660.0	MO, HA, PA, PV, IM, CI
HM V	16	53.9	4.6	2.3-140.4	CI, PV, PA, MO
HM VI	2	7.0	0.8	6.5-7.5	MO, PV
SH III	5	16.4	4.9	1.7-34.1	CI, IM
SH IV	76	37.6	3.0	0.4-614.2	IM, CI, PV, PA, HA, TK, MO
SH V	10	107.8	30.3	12.4-471.9	MO, PA, PV, CI, IM
AW VI	43	39.6	2.7	0.4-240.2	MO, TK, HA, PA, PV, CI, IM, LA, YU

[a]YU = Yuma, MO = Mohave, PA = Parker, PV = Palo Verde, TK = Topock, HA = Havasu, CI = Cibola, LI = Limitrophe, LA = Laguna, IM = Imperial.

Table 25. Ranks for community/structure types (habitats) used in Spearman rank correlations tests for all habitats and first terrace habitats (CW, SM, SC). Ranks are from low to high values for total area (AE), structure type (ST), number of patches (NP), and mean patch size (MP).

	All habitats				First terrace habitats			
Community/ structure type	Total area	Structure	Number of patches	Mean patch size	Total area	Structure	Number of patches	Mean patch size
HM VI	1	22	3.0	1.0	--	--	--	--
SC II	2	3	1.5	17.0	1	3	1.5	13.0
SM II	3	3	1.5	16.0	2	3	1.5	12.0
CW II	4	3	6.0	4.0	3	3	4.5	3.0
SH III	5	7	6.0	5.0	--	--	--	--
SC I	6	1	6.0	9.0	4	1	4.5	7.0
SC III	7	7	12.0	2.0	5	5	7.0	1.0
CW III	8	7	13.5	3.0	6	5	8.5	2.0
SM III	9	7	13.5	6.5	8	15	6.0	4.5
CW VI	10	22	10.0	6.5	8	15	6.0	4.5
HM III	11	7	8.0	22.0	--	--	--	--
CW V	12	17	15.0	8.0	9	13	10.0	6.0
HM V	13	17	11.0	21.0	--	--	--	--
SM VI	14	22	4.0	20.0	10	15	3.0	16.0
SH V	15	17	9.0	24.0	--	--	--	--
CW IV	16	12	19.5	10.0	11	9	12.5	8.0
SC VI	17	22	18.0	18.0	12	15	11.0	14.0
AW VI	18	22	17.0	15.0	--	--	--	--
SH IV	19	12	21.0	14.0	--	--	--	--
SM V	20	17	19.5	11.0	13	13	12.5	9.0
HM IV	21	12	16.0	23.0	--	--	--	--
SC V	22	17	22.0	19.0	14	13	14.0	15.0
SM IV	23	12	23.0	13.0	15	9	15.0	11.0
SC IV	24	12	24.0	12.0	16	9	16.0	10.0

Results of Spearman ranks (r_s, n = 24)

	All habitats				First terrace habitats			
	AE	ST	NP	MP	AE	ST	NP	MP
AE	--	0.416	0.854	0.452	--	0.744	0.908	0.533
ST	0.025	--	0.371	0.262	0.001	--	0.604	0.542
NP	0.001	0.650	--	0.130	0.001	0.010	--	0.159
MP	0.025	NS	NS	--	0.025	0.025	NS	--

type and number of patches were also significantly associated ($P \leq 0.05$). Mean patch size was not associated with either number of patches or structure types among all habitats.

First terrace plant communities were subject to fewer direct human impacts than second terrace communities. Significant associations were stronger than those described above between total area and structure type ($P \leq 0.001$), number of patches ($P \leq 0.001$), and mean patch size ($P \leq 0.025$). Also, significant associations were found comparing structure type with number of patches ($P \leq 0.01$) and mean patch size ($P \leq 0.025$). As with all habitats considered, there was no association between number of patches and mean patch size for first terrace habitats.

These results confirm earlier suggestions that the higher structured habitats not only are the smallest in total area, but they also contain fewer patches with smaller mean patch size, especially between the river levees. The evidence presented here points towards the eventual disappearance of native cottonwood-willow habitat, despite some recent but local regeneration. The conversion of most of the remaining honey mesquite to agriculture combined with saltcedar's dominance in the first terrace has resulted in an ever expanding monoculture of manipulated habitats.

6.3 MARSH HABITATS ON THE LOWER COLORADO RIVER

Emergent vegetation, marshes composed primarily of cattail, bulrush, or cane, covered just over 2,000 ha (5,000 acres) in 1986 and has increased overall since 1976 (Table 26) (Anderson and Ohmart 1984c). The historical amount of emergent habitats along the Colorado River is debatable, but presently these stands are found throughout the system, with the largest stands behind Imperial and Parker Dams and enclosed by levees above Topock. The large emergent wetlands behind dams and impoundments are mostly composed of type 1, which is nearly 100% cattail/bulrush. Type 1 composed 45% of all marsh habitat on the lower Colorado River in 1986.

Overall, emergent wetlands have increased 113% from 1976 to 1986, but not all marsh types have increased. Type 3 (25%-50% cattail/bulrush, many trees, and grasses interspersed), type 6 (cane), and type 7 (open water) increased between 1983 and 1986. Types 2, 4, and 5 (varying degrees of cattail/bulrush with few trees and grasses interspersed) declined between 1983 and 1986.

Many of these changes can be attributed to the 1983-1984 flooding events. Types 2, 4, and 5 are mostly found along the river channel and were subjected to scouring and submergence from the floodwaters. Increases in type 7 would be related to extensive submergence of former types 2, 4, and 5, while increases in type 3 are probably related to emergents growing within flooded terrestrial riparian habitats. Impoundments and reservoirs were operating well below capacity whenever possible during the flooding, thus influencing the spread by type 1 marshes at Topock and Lake Havasu, while type 6 spread in the Imperial Division.

Long-term changes in emergent habitat types cannot be anticipated at this time. Marsh vegetation does recover quickly and can spread into many areas where standing water has been retained well after floods have receded. Many areas in and around Cibola National Wildlife Refuge, once covered in mesquite and saltcedar, are now dominated primarily by cattail.

Table 26. Changes in emergent vegetation types among years on the lower Colorado River. Data from Anderson and Ohmart (1984c).

	Hectares			Percent change		Overall change
Type[a]	1976[b]	1983	1986	1976-1983	1983-1986	1976-1986
1	--	1,590	2,263	--	+42	--
2	--	553	292	--	-47	--
3	--	496	743	--	+50	--
4	--	229	158	--	-36	--
5	--	437	177	--	-60	--
6	--	254	703	--	+176	--
7	--	502	695	--	+38	--
Total	2,361	4,061	5,031	+72	+24	+113

[a]Marsh type definitions: 1 = nearly 100% cattail/bulrush; 2 = nearly 75% cattail/bulrush, some trees, grasses, cane, and open water; 3 = about 25%-50% cattail/bulrush, many trees and grasses interspersed; 4 = about 25%-50% cattail/bulrush, few trees and grasses interspersed; 5 = about 50%-75% cattail/bulrush, few trees and grasses interspersed; 6 = nearly 100% cane, little open water; and 7 = open marsh (75% water), includes sandbars and mudflats.

[b]Marsh types were not defined until 1981.

The longevity of these new Cibola marshes is dependent on the amount of seepage of water from the river through the levees. Overall, marshes are expected to stabilize in total area and type, but if river flow conditions again become variable, then marsh types and change in total area could change rapidly.

CHAPTER 7. PLANT COMMUNITIES

7.1 AQUATIC MICROPHYTES

Algae are seasonally abundant in the mainstream Colorado River especially on the harder substrates found near dams (Minckley 1979). Diatoms (Bacillariophyceae) are the most common algae, occurring on substrates of stabilized sand, bedrock, riprap, and as epiphytes on vascular plants and larger algae. Cladophora glomerata (Chlorophyaceae) often become dense in riffle-like habitats <0.5 m (<1.5 ft) deep. Blue-green algae or cyanobacteria (Cyanophyceae) occupy quieter areas, forming mats on soft substrates. Common blue-green algae genera include Oscillatoria, Phormidium, and Spirulina, with Nostoc occurring locally in shallow riffles. A rhodophycean (Thorea sp.) and a semimarine chlorophycean (Pseudouvella sp.) are rare in the more saline waters of the Imperial Dam area and the reach south of Yuma.

Overall, phytoplankton is scarce along the lower Colorado River (Crayton and Sommerfeld 1978), except near impoundments. However, during Minckley's (1979) study of the Colorado River's aquatic biota, local blooms of algae and cyanobacteria were present throughout the study area in backwaters and slow-moving drains. In addition, there were differences in the distribution of phytoplankton taxa among reservoirs with cyanobacteria becoming most abundant in the lower reservoirs (e.g., Lake Havasu; Everett et al. 1973). Pigment concentrations were used to indirectly indicate the presence of phytoplankton and benthic and epiphytic algae scoured into the current or moved by accumulation of gases and flotation from calmer areas. Although there is a trend for pigment (primarily chlorophyll a) to increase from upstream to downstream, absolute differences are not large (see Table 9). Phosphate-phosphorus tend to be higher in the lower reaches, paralleling higher productivity by microphytes. Higher electroconductivity downstream may also enhance algal populations. The narrow range of variation and relatively small buildup of pigment through the lower Colorado River indicates a rather constant, downflow displacement of organic materials, balanced by degradation, storage, or use within the system, rather than a pattern of downstream eutrophication (Minckley 1979).

Pigment concentrations were consistently higher in backwaters when compared to those in adjacent mainstream areas. The trend for greater amounts of pigments downstream also holds true in backwaters. Canals generally have chlorophyll concentrations similar to those found in the mainstream. Inflow of drains to the mainstream resulted in local increases in pigment concentrations but these were dissipated through dilution.

7.2 AQUATIC MACROPHYTES

Submergent macrophytes are most prevalent in unchannelized sections of the mainstream in the Mohave Valley, Havasu, and Parker reaches of the river. This plant community is sparsely represented in Imperial National Wildlife Refuge and south of Yuma and is largely absent elsewhere in the river. The 1983 floods greatly reduced the biomass of this plant community, even in areas where it was most prevalent before the flood.

Macrophyte stems and leaves increase surface area and living space for microphytes. Beds of aquatic macrophytes also accumulate materials near their bases to provide additional rooting space for the plants themselves and stable, fine-grained substrate for colonization by invertebrates. Accumulation of autochthonous and allochthonous organic debris in beds of aquatic macrophytes is fed upon by many animals including fishes (Minckley 1979).

Sago pondweed (Potamogeton pectinatus) is the most common species in the mainstream, especially near Parker within the Colorado River Indian Reservation. Sago pondweed is most common in monotypic beds in deep water (to 4.5 m [14.8 ft]) and often in places where current exceeds 1 m/sec (3 ft/sec). The 1983 flood greatly reduced the distribution and abundance of Sago pondweed, with effects observable in declines of American wigeon (Anas americana) and gadwall (A. strepera) (Anderson and Ohmart 1988). Water milfoil (Myriophyllum spicatum subsp. exalbus) and parrotfeather (Myriophyllum brasiliense) are collectively second in abundance but do not occur with Sago pondweed. Milfoil and parrotfeather form dense beds in shallow (to 2.5 m [8.2 ft]) water flowing <0.5 m/sec (<1.6 ft/sec). Charophytes (Chara spp.) are third in abundance and occur in eddies or other places where currents are not too strong, but they also are interspersed with other aquatic macrophytes in the channel. Hornwort (Certophyllum demersum) is fourth in dominance and is found in calm areas. Other aquatic macrophytes include leafy pondweed (Potamogeton foliosus), common pondmat (Zannichellia palustris), and common water nymph (Najas guadalupensis). These plants stabilize fine-grained bottoms in shallow places where daily fluctuations of the water surface are minimal.

Shorelines and calm places near backwaters often are vegetated by holly-leaved water nymph (Najas marina). Bladderworts (Utricularia spp.) and duckweeds (Lemna spp.) most often occur in lentic habitats and otherwise slow-moving water, but occur uncommonly with other aquatic macrophytes in the mainstream. Species of aquatic macrophytes found in canals and drains are the same as those found in the mainstream; however, leafy pondweed replaces Sago pondweed as the dominant species. The two species of Myriophyllum are rare in these habitats.

Prior to 1983, standing crops of emergent macrophytes ranged to maxima of 1,322 g/m^2 (47 oz/ft^2) near Parker on the Colorado River Indian Reservation and 528 g/m^2 (19 oz/ft^2) south of Morelos Dam (Minckley 1979). The means of samples for these two areas, however, ranged from 24 to 805 g/m^2 (0.8 to 28 oz/ft^2) and 0.9 to 254 g/m^2 (0.03 to 9 oz/ft^2), respectively. These values indicate a relatively depauperate macrophyte flora compared with streams of temperate eastern North America, the Pacific Northwest, and tropical South America (Westlake 1975; Minckley 1979). However, where submergent macrophytes occur they are important to aquatic fauna (Minckley 1979).

Drift material is primarily composed of aquatic macrophytes and is an important component of the stream (Minckley 1979). Comparison of drift samples from near Parker and Morelos

Dam indicated that concentrations of macrophytic plants are variable but are higher in the Parker area. Sago pondweed composes up to two-thirds of drift by wet weight, with the remainder consisting of Myriophyllum spp., hornwort, water nymph, charophytes, emergent vegetation, algae, and miscellaneous terrestrial plant material. Canals and drains sampled in the Yuma Valley were similar in drift concentrations to those found in the Parker area mainstream (Minckley 1979).

7.3 EMERGENT PLANTS

Shallow shorelines adjacent to mainstream backwaters and islands are covered by emergent plant species typical of marshes. Giant bulrush (Scirpus californicus) grows in water to 1.5 m (5 ft) deep and extends as high as 3 m (10 ft) above the surface. Cattail is often found with giant bulrush but occurs in shallower water to 1 m (3 ft) deep. Giant bulrush forms thick stands along unmodified banks, creating a broad (1 to 5 m [3 to 18 ft]) zone of quiet water adjacent to relatively swift currents, while cattail forms beds on sloping, stabilized or aggrading banks that extend as far as 15 m (49 ft) from shore, often on the quiet sides of bends. Where the currents contact beds of giant bulrush or cattail, the mats of roots and rhizomes are often undercut for distances of more than 2.5 m (8 ft). Cane is a common emergent plant in the lower reaches of the river from Imperial National Wildlife Refuge to the U.S.-Mexico International Border. Giant reed (Arundo donax) is less common than cane and occupies less hydric parts of the shoreline (Minckley 1979).

Backwaters, ponds, and deltas (e.g., entering Lake Havasu) become extensive marshes rapidly colonized by sedges, three-corner bulrush (Scirpus americanus), cattail, and reeds. A rising water table (with unchecked delta formation) and flooding along the Bill Williams River has facilitated the advance of cattail upstream from the delta since 1974 at the expense of broadleaf riparian habitats (Hunter et al. 1987). Canals and drains often become choked with cattail and sedges, while grass (primarily Bermuda grass [Cynodon dactylon]) lines the banks.

A number of smaller emergent plant species occur in the understories within marsh communities and along banks that are not permanently flooded. These species include pennywort (Hydrocotyle verticillata), water hyssop (Bacopa monneri), smartweed (Polygonum fusiforme), spearmint (Mentha spicata), and a diversity of grasses and sedges (Leptochloa uninerva, Paspalum dilatatum, Cyperus strigosus, C. erythrorhizos, Eleocharis parcula, and E. caribea). Bermuda grass is common in disturbed areas along the river, especially along dredge spoils, canals, and drains. This species also spreads to other more natural areas. Saltgrass is locally abundant, especially on saline soils with surface horizons of loam or clay.

Data for standing crops of submergent and emergent vegetation indicate backwaters and drains are highly productive in contrast with mainstream communities (Westlake 1975; Minckley 1979). These habitats are extremely important to a large number of animal species for breeding and foraging. Many aquatic invertebrates and fish species use these habitats for cover during breeding, and for protection from higher-order predators. Crayfish (Procambrus sp.) are abundant in the shallow portions of emergent stands, as are their predators, which include birds (e.g., rails and herons) and mammals (e.g., raccoons [Procyon lotor], skunks, etc.). Many bird species nest in or near these habitats, including the endangered (Federal list) Yuma clapper rail and the Arizona and California State-listed black rail (Laterallus jamaicensis; in three-corner bulrush). Muskrats and beaver are often common in emergent wetlands.

7.4 WOODY RIPARIAN PLANTS

Woody riparian species are the most studied plants on the lower Colorado River. Details on the dynamics and classification of woody riparian communities are summarized in Chapters 1, 2, 6, and Appendix A.

Despite the rising interest in woody riparian communities, little is known about all the conditions necessary for successful regeneration of riparian plants. Initial flooding is necessary to provide nursery beds for seedlings of broadleaf trees (Brady et al. 1985; Brock 1985). Sandy soil, shallow water table, and low salinity (<2,000 µmhos/ml) are all essential for natural regeneration. Few places on the lower Colorado River exist at present that maintain these conditions. In addition, the reduction of nutrients flowing downstream may have dramatic effects on regeneration potential, especially since one of the more important aspects of annual flooding was to replenish nutrients in first terrace soils for cultivation by the Amerinds of the region. Although there was some natural regeneration after the 1983 floods, it is unlikely that recruitment of mature cottonwood and willow will be widespread in the near future. Many trees will succumb to high salinities or unpredictable water-table depth. Other riparian woody plants (including saltcedar, mesquite, arrowweed, and quail bush) equally need saturated soils for germination but are able to tolerate heavier soil, higher salinities, and greater depths to the water table (Anderson and Ohmart 1982b, unpubl. data). These latter plant species are more likely to develop into mature stands than cottonwoods and willows.

Woody riparian vegetation is important for a vast array of animal species. These plant communities contribute significantly to fish habitat when floods wash trees and other organic debris into the river and by providing shade along banksides. Remains of fallen cottonwood and willow trees persist as logs and debris in the mainstream and in backwaters, which is important for many aquatic organisms. Vertical and horizontal diversity in woody riparian habitats are important overall for supporting a tremendous diversity of animals, both invertebrates and vertebrates (especially birds).

7.5 DESERT VEGETATION

Desert vegetation bordering the lower Colorado River sorts into two basic categories. The primary desert habitat is sparsely vegetated uplands dominated by creosote bush (Larrea divaricata subsp. tridentata). Woody plants interspersed among creosote bushes include catclaw acacia (Acacia greggii), ocotillo (Fouquieria splendens), ironwood (Olneya tesota), and foothills or blue palo verde (Cercidium floridum). In the Mohave Valley, Joshua tree (Yucca brevifolia) is found locally. On the Arizona side, primarily near Parker and Ehrenberg, saguaro cacti (Carnegiea gigantea) reach the western limit of their range; historically, saguaro occurred very locally on the west side of the river near Bard and Parker. Many species of grasses and forbs are found in desert upland habitats, some of which are important food items for ants, quail, rodents, and ungulate mammals. Rocky, gravelly, and sandy substrates predominate and all are important for various species of desert reptiles and small mammals.

Cutting through the desert uplands and flats are washes formed by surface water from occasional, torrential rains. These desert washes support riparian plant species that cannot survive in the drier uplands. Typical desert trees such as blue palo verde and ironwood frequently grow along these washes, and are taller and lusher than their conspecifics on drier upland soils. In addition, honey mesquite may be found in desert washes, especially nearer the confluence between the river and the larger washes. A common obligate in desert washes is smoke tree (*Psorothamnus spinosus*). Leguminous trees in desert drainages are often infested with mistletoe, not unlike mesquite habitats near the river. Frequently, there is a lush growth of shrubs (i.e., *Atriplex*, *Suaeda*, brittlebush [*Encelia farinosa*]), annual forbs, and grasses along these drainages. Desert washes form a floristic and faunal transition zone from purely riparian to purely desert habitats. Birds in particular show this transition from riparian to desert communities (Szaro and Jakle 1985). Herpetofauna and mammals in desert washes basically are of desert origin, although many species are either unique to or dependent on desert wash habitats.

7.6 LISTED SPECIES AND THREATENED HABITATS

At present, there are no Federal- or State-listed endangered or threatened plant species occurring in the lower Colorado River Valley. However, several plant community types are in danger of extirpation from the system. Primary among these are the broadleaf habitats dominated by cottonwood and willow. Healthy and mature stands are all but gone from the system. Cottonwoods, especially, are now very rare. Local regeneration of cottonwoods and willows is insufficient to return healthy populations of these species to the entire lower Colorado River. Drastic changes in water flow regimes would be necessary for extensive, successful regeneration to occur.

Honey mesquite stands, though more widespread than cottonwood and willow, are in jeopardy from extensive clearing. Agricultural development and cutting for fire wood may continue to reduce and isolate remaining stands. Regeneration of honey mesquite is virtually nonexistent, as terrace formation has been halted with human development and river flow control. There is an immediate need to preserve remaining honey mesquite stands on the Colorado River Indian Reservation and at the Soto Ranch north of Needles.

Screwbean mesquite reaches its greatest abundance and distribution for both Arizona and California along the Colorado River. This tree is much more common now than it was at the turn of the century. However, screwbean mesquite's recent abundance has been severely diminished since its peak in the 1960's. Losses are due to widespread clearing, fires, and flooding, all of which act to favor saltcedar, the major understory plant in screwbean mesquite stands. This trend of succession from screwbean mesquite to saltcedar is expected to continue given present management practices.

On the lower Colorado River, aquatic vegetation occurring in unmodified channels was severely reduced by the 1983-1986 floods. Sago pondweed was reduced by these floods and has not yet recovered. Return to normal controlled flows may allow aquatic plant populations to eventually recover. Present and future plans to channelize the remaining stretches in the Parker, Yuma, and Limitrophe Divisions would, in effect, prevent any large-scale recovery of this plant community.

CHAPTER 8. INVERTEBRATE COMMUNITIES

8.1 AQUATIC INVERTEBRATES

Zooplankton in the lower Colorado River consists of protozoans, rotifers, water bears, water fleas, seed shrimp, copepods, and amphipods (Table 27). Zooplankton numbers in the main channel are inversely proportional to flow, with greatest abundance during low flows (Marsh and Minckley 1985). Numbers are typically highest during late fall and winter and in quieter backwaters. Copepods were the most abundant taxa throughout the system among zooplankton (Marsh and Minckley 1985).

Benthic and sessile invertebrates are typically sparse in large erosive systems like the Colorado River. However, the placement of large dams has acted to disrupt typical substrate composition and the associated presence and abundance of benthic and sessile species. Large rivers generally have extensive beds of shifting, fine-grained bottom materials; however, larger materials accumulate immediately below dams.

Benthos is relatively well developed immediately below Davis and Parker Dams. Filter feeders are common, with simuliid dipterans, hydropsychid trichopterans, and Asiatic clams (Corbicula fluminea) dominating (Table 28). These groups indicate the presence of large concentrations of finely divided particulate organic matter from upstream reservoirs (Minckley 1979). Taxa below Davis Dam include heptageniid mayflies, hydrophilid beetles, and turbellarian worms. Below Parker Dam these taxa, along with baetid mayflies and tipulid dipterans, are found in abundance.

Densities and diversities of benthos decline sequentially with distance from both Davis and Parker Dams. Variations introduced by a series of dams separated by highly modified channel does not suppress this trend. Backwaters support greater numbers, diversity, and biomass per unit area than does the mainstream (away from dams; Minckley 1979). Taxa associated with more typical large river reaches include oligochaete worms, dragonfly naiads in soft or sandy bottoms, damselfly naiads, culicid and tabarid dipterans, dytiscid and hydrophilid beetles, and pulmonate snails. These taxa are all associated with beds of aquatic plants. All of these taxa are more abundant in backwaters than in the adjacent mainstream.

During the last decade, hydropsychid trichopterans have become an extreme nuisance to residents and tourists in the Parker area, while simuliids have become pests immediately below Davis Dam (Gronowski 1987a,b). The adult stage for both groups has become so abundant as to affect outdoor activities, which, in turn, has affected the economy. Political pressure has brought demands on local, State, and Federal agencies to address these problems. Proposed solutions include application of insecticides (including 95% malathion), changes in water-release patterns from Davis Dam, and the reintroduction of insectivorous native fish. Presently,

Table 27. Major aquatic invertebrate taxa recorded from the lower Colorado River (Minckley 1979, Marsh and Minckley 1985).

Taxa/Common name descriptor

- Protozoa[a]
  - Rhizopoda
- Rotataria[a] -- rotifers
- Platyhelminthes
  - Turbelleria[b] -- flatworms
    - *Planaria*
    - *Dugesia*
- Mollusca
  - Gastropoda
    - *Physa virgata*[b]
    - *Radix auricularia*[b]
    - *Gyraulus parvus*
  - Pelycepoda
  - *Corbicula fluminea*[a] -- Asiatic clam
- Nematoda -- roundworms
- Annelida -- segmented worms
  - Oligochaeta[a] -- aquatic earthworms
  - Hirundinae[b] -- leeches
- Tardigrada[b] -- water bears
- Arthropoda
  - Crustacea
    - Branchipoda
      - Cladocera -- water fleas
        - *Acanthleberis*
        - *Alara*[c]
        - *Alonella*
        - *Bosmina*[c]
        - *Camptocerus*
        - *Ceriodaphinia*[b]
        - *Chydorus*[c]
        - *Daphnia*[b]
        - *Kurzia*
        - *Macothrix*
        - *Moina*
        - *Polyphemus*
        - *Simocephalus*
    - Astraceda[b] -- seed shrimps
    - Copepoda -- copepods
      - Calanoida[b]
      - Cyclopoida[b]
      - Harpactacoida
        - Naplius[a] -- (undifferentiated larvae)
        - Copepodid[c] --(undifferentiated larvae)
  - Malacostraca
    - Amphipoda[b] -- amphipods
    - Decapoda
      - Palaemonidae
        - *Palaemonetes paludosus*[c] -- freshwater shrimp
      - Astacidae
        - *Procambarus clarki*[c]-- crayfish
  - Insecta
    - Emphemeroptera[c] -- mayflies
      - Heptagenildae -- stream mayflies
      - Baetidae[c] -- small mayflies
        - *Baetis*
        - *Callibaetis*
      - Tricorythodes
        - *Tricorythodes*
      - Caenidae
        - *Caenis*
    - Odonata[c] -- dragonflies/damselflies
      - Coenagrionidae -- narrow-winged damselflies
        - *Enallagma*
        - *Hyponeura lugens*
        - *Ischnura perparva*
      - Gomphidae -- clubtails
        - *Gomphus*
      - Libellulidae -- common skippers
    - Hemiptera - true bugs
      - Belostomatidae -- giant waterbugs
      - Corixidae[c] -- water boatmen
        - *Corisella*
        - *Trichocorixa*
    - Neuroptera
      - Corydalidae -- dobson flies
    - Trichoptera -- caddisflies
      - Hydropsycidae[c] -- net-spinning caddisflies

(Continued)

Table 27. (Concluded)

Taxa/Common name descriptor
Smicridae utico -- primitive caddisfly
Glossosomatidae
Hydroptilidae* -- micro-caddisflies
Leptoceridae -- long-horned caddisflies
Nectopsyche
Lepidoptera -- moths/butterflies
Danaidae -- milkweed butterflies
Pyralidae -- pyralid moths
Paragyraetis
Coleoptera -- beetles
Haliplidae -- crawling water beetles
Peltodytes
Dytiscidae[b] -- predaceous diving beetles
Hydrophilidae[c] -- water scavenging beetles
Elmidae -- riffle beetles
Diptera -- flies
Tipulidae[b] -- crane flies
Polymeda
Chaoboridae -- phantom midges
Chaoborus
Culicidae[c] -- mosquitoes
Culex
Psychodidae -- sand flies
Psychoda
Ceratopogonidae[c] -- punkies
Palpomyia
Sphaeromias
Simuliidae[c] -- black flies
Chironimidae[a] -- midges
Tabanidae -- deer flies
Chrysops
Dolichopodidae -- long-legged flies
Empididae -- dance flies
Ephydridae -- shore flies

[a]Taxa abundant and widespread throughout.
[b]Taxa uncommon, but widespread or locally fairly common.
[c]Taxa locally abundant or fairly common and widespread.

Table 28. Summary of diversity, numbers, and biomass (dry weight) of benthic invertebrates from the lower Colorado River, 1974-76. Adapted from Minckley 1979; see Table 2 (Minckley 1979) for periods of sampling.

Divisions	Sampling method	Number of samples	Number of taxa	Individuals/m^2	kg/ha
Mohave Valley					
Mainstream	Surber	21	13.5±3.6	1,954±493	8.235±6.504
Mainstream	Ekman	14	3.9±1.2	409±254	0.024±0.007
Backwater	Ekman	6	6.7±2.6	2,450± 1.514	6.681±1.279
Topock Gorge					
Mainstream	Ekman	19	3.7±1.4	262± 44	1.217±0.402
Havasu					
Mainstream	Ekman	5	3.0±1.4	328±217	0.159±0.077
Backwater[a]	Ekman	27	2.0±0.2	96± 10	0.321±0.112
Backwater	Ekman	7	2.0±1.3	1,373±460	2.081±1.007
Parker					
Mainstream	Surber	47	12.3±2.6	1,277±314	10.017±3.390
Palo Verde					
Mainstream	Ekman	27	4.6±0.9	121± 17	0.551±0.220
Backwater	Ekman	11	3.4±1.1	371± 87	1.619±1.860
Cibola					
Mainstream	Ekman	15	2.3±0.5	176± 41	0.088±0.024
Backwater	Ekman	5	3.0±1.8	759±341	8.899±5.307
Imperial					
Mainstream	Ekman	13	3.2±1.3	136± 67	2.071±2.096
Backwater	Ekman	16	3.7±0.3	720±215	0.125±0.051
Laguna					
Backwater	Ekman	4	2.5±1.3	108± 45	0.156±0.063
Yuma					
Mainstream	Ekman	19	4.5±1.1	1,307±260	2.230±1.753
Limitrophe					
Mainstream	Ekman	19	3.4±0.6	889±324	1.808±0.382
Backwater	Ekman	32	6.5±0.8	1,202±226	3.931±1.151

[a]Samples from the main body of Lake Havasu.

introductions of razorback suckers are being used to consume hydropsychid larvae in the Parker area (Burton 1987; Gronowski 1987a,b; Metz 1987). Recent declines of simuliids in the Davis Dam area are suspected of influencing recent declines in local bass and trout fisheries.

The high flow year of 1983 resulted in increased seepage which, in turn, increased the amount of stagnant water, e.g., 200 ha (500 acres) near Yuma, 80 ha (200 acres) at Cibola National Wildlife Refuge, 80 ha (200 acres) near Ehrenberg, and 2,800 ha (7,000 acres) in the Mohave Valley

(Levy et al. 1987). Increases in encephalitis-carrying mosquitos became a major concern. One species, Culex tarsalis Coq., a carrier of St. Louis encephalitis and Western equine encephalitis, was especially abundant (Levy et al. 1987). Four confirmed and three suspected St. Louis encephalitis cases in humans were reported during that period on the lower Colorado River. Larvacides to control mosquitos were Abate 26 (2% granular temphos) and granular Bacillus thuringensis var. israelensis (Bti). The adulticide cythion (91% malathion) was applied during night flights. The control program occurred from mid-August into early November 1983, and again in the summer of 1984, and covered about 60,000 ha (150,000 acres) along the lower Colorado River (Levy et al. 1987).

Aquatic invertebrates constitute major food sources for vertebrate species, primarily fish (Minckley 1979). Zooplankton (mostly typical of limnetic situations in reservoirs were found in trout, threadfin shad (Dorosoma petenense), red shiner (Notropis lutrensis), and bluegill (Lepomis macrochirus) (Minckley 1979). In addition, these invertebrate taxa plus ostracods were found in carp (Cyprinus carpio), largemouth bass, green sunfish (Lepomis cyanellus), and black crappie (Pomoxis nigromaculatus). Benthic invertebrates formed parts of the diet of all fishes studied by Minckley (1979). Chironomids, simuliids, and other dipteran larvae were important food items for trout, carp, red shiner, yellow bullhead (Ictalurus natalis), bluegill, and green sunfish. Hydropsychid trichopterans were important food items for trout. Emphemeropteran nymphs and hellgrammites were important for smallmouth bass (Micropterus dolomieui) and odonate naiads were important for warmouth (Lepomis gulosus). Paleomoneid shrimp are abundant on the lower Colorado River but are only eaten by black crappie, in dense aquatic vegetation. Aquatic insects are also important for many waterfowl species (Anderson and Ohmart 1988).

Two large invertebrates, crayfish and Asiatic clam, are important food items to a number of vertebrate taxa. Crayfish (primarily Procambarus clarki) apparently were not present before 1900 and probably increased through bait introductions or natural expansion (Ohmart and Tomlinson 1977). Extensive, shallow cattail/bulrush marshes are very important habitats for crayfish (Loudermilk and Moore 1983). The recent increase in emergent habitats since the mid-1940's undoubtedly influenced the establishment of these decopods throughout the system. Little data exist on the ecology of crayfish on the lower Colorado River, although it probably does not differ greatly from natural situations. At one time crayfish were thought to be dormant in winter; however, recent data indicate that they remain active but are more reclusive than in summer (Eddleman et al. 1987). Crayfish are important food items for large carnivorous fish species (especially catfish and smallmouth bass), bullfrogs (Rana catesbeiana), spiny softshell (Trionyx spiniferus), garter snakes (Thamnophis sp.), many birds (including the endangered Yuma clapper rail), and several medium-sized carnivorous mammals (e.g., raccoon, striped skunk [Mephitis mephitis]).

A second important large invertebrate is the exotic Asiatic clam. The Asiatic clam could have entered the Colorado River system as early as the mid-1950's, when it was first recorded in abundance along the Coachella Valley (Ingram 1959; Ingram et al. 1964). The free-floating larvae cause serious problems by clogging drains in irrigation canals and are of special concern in California (Ingram et al. 1964). Ideal conditions for Asiatic clams seem to include clear water and a well-developed plankton food base (Rinne 1974). River reaches immediately below Davis and Parker Dams fit these criteria and harbor very large Asiatic clam populations (Minckley 1979). In more turbid waters, Asiatic clams filter relatively large amounts of water very quickly. Organic and inorganic materials not digested are often excreted as "pseudofeces" to clear the gills in very turbid situations. Along most river reaches, the Asiatic clam is one of the most abundant macroinvertebrates present in both lotic and lentic habitats. Asiatic clams are eaten by carp, channel catfish, yellow bullhead, redear sunfish (Lepomis microlophus), and mouthbrooder (Tilapia mossambica). Asiatic clams are important to Barrow's goldeneyes (Bucephala islandica), common goldeneyes (B. clangula), and buffleheads (B. albeola), among birds, and also to medium-sized carnivorous mammals.

8.2 TERRESTRIAL INVERTEBRATES

Information on diversity and biomass of terrestrial invertebrates is almost all from studies of riparian vegetation (Cohan et al. 1978; Anderson et al. 1982). Each of the six major riparian plant associations was sampled by insect net sweeping 4,000 times monthly from August 1976 to June 1978. In addition, numbers of annually emerging Apache cicadas (Diceroprocta apache) were counted in 1982 to quantify the abundance of this important insect (Anderson et al. unpubl. data). Taxa and habitat use among seasons are discussed on the ordinal level except for a few important families or species.

Overall, invertebrate biomass (primarily insects and arachnids) is highest seasonally from April to August, with peaks in April and May (Figure 33). Dramatic increases were noted in all habitats between March and April, and sharp declines were found for most habitats between August and September. Lowest biomass was found for all habitats in January and February.

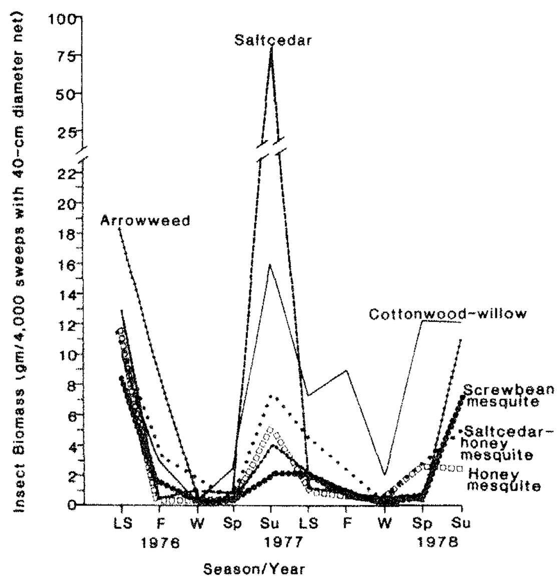

Figure 33. Insect biomass (excluding cicadas) among riparian habitats over 2 years on the lower Colorado River.

Cottonwood-willow habitat consistently supported high invertebrate biomass, especially from the spring of 1977 through to the summer of 1978. Biomass was high in cottonwood-willow habitat through the winter of 1977-1978, while biomass was very low in all other riparian habitats; it was a relatively mild winter on the lower Colorado River. Arrowweed habitat supported high invertebrate biomass, mostly orthopterans (primarily grasshoppers), from August through October

1976 and again in May 1978. Saltcedar habitat ranked extremely high in biomass of terrestrial invertebrates during summer 1977 due to very high numbers of cicadellids (leafhoppers; order Hemiptera); this family often constituted the most abundant taxon found in all riparian habitats during summer.

Cottonwood-willow habitat consistently supported the highest arthropod biomass for more taxa than any other habitat across seasons (Table 29). Saltcedar, arrowweed, and saltcedar-honey mesquite habitats all became important for a number of taxa during summer. Orthopterans (including grasshoppers, mantids, katydids, crickets, and walking sticks) consistently accounted for much of the biomass among all habitats, especially during summer and late summer. Leafhoppers and cicadas both are abundant among most habitats and often account for the majority of seasonal biomass, especially during summer. Hymenoptera (bees, wasps, and ants) occur in large numbers in the spring and contribute much to the invertebrate biomass in cottonwood-willow, saltcedar, and honey mesquite habitats. Lepidoptera (butterflies, moths, and their larvae) account for most of the biomass during spring in honey mesquite.

Terrestrial invertebrates are important as food for many terrestrial vertebrates, especially insectivorous lizards, birds, and bats. In addition, terrestrial invertebrates found on water surfaces (accidentally or otherwise) are important food items for fish. Invertebrate taxa, including Cicadidae, Lepidoptera, Diptera, and Hymenoptera, are among the most prevalent food items found in the diets of vertebrates (Minckley 1979; Anderson and Ohmart, unpubl. data).

Of all the terrestrial invertebrates found on the lower Colorado River, the Apache cicada is an extremely important food item. The Apache cicada emerges annually beginning in mid-June in riparian vegetation. Tremendous numbers are found in cottonwood-willow, screwbean mesquite, saltcedar-honey mesquite mix, and, especially, saltcedar habitats (Table 30). The timing of cicada emergence coincides closely with the peak breeding period for many bird species in cottonwood-willow communities. Most breeding birds in cottonwood-willow forage primarily for cicadas. Energetic calculations suggest that many more cicadas exist then could be possibly used by the breeding bird community (Rosenberg et al. 1982). Interestingly, cicadas are most abundant in saltcedar habitats. Glinski and Ohmart (1984) hypothesized that saltcedar provides greater surface area for cicada egg-laying because of the intricate branching of leaves compared with that of native riparian trees. Many of the birds that feed on cicadas are rare or absent in saltcedar. However, after saltcedar stands burn, the emerging cicadas attract many bird species which become abundant in this habitat (Table 31). Adult cicadas begin dying in large numbers by mid-August, after most avian breeding activity is over.

<u>Agricultural Invertebrates</u>

Invertebrates associated with agriculture are important in two ways to the overall system ecology of the lower Colorado River. Insects provide an abundant food resource for other invertebrates (insects and arachnids) and many vertebrates, especially wintering birds. However, many insects are considered pests by farmers; thus, insecticides are widely and liberally applied. The effects on the system of extensive pesticide application are just now being assessed.

Table 29. Terrestrial arthropod taxa and their seasonal occurrence and major riparian habitats used. CW = cottonwood-willow, SC = saltcedar, AW = arrowweed, SH = saltcedar-honey mesquite, SB = screwbean mesquite, HM = honey mesquite. Data from Anderson and Ohmart (unpubl.).

	Season/habitat																													
	Fall						Winter						Spring						Summer						Late Summer					
Order/family[a]	CW	SC	AW	SH	SB	HM	CW	SC	AW	SH	SB	HM	CW	SC	AW	SH	SB	HM	CW	SC	AW	SH	SB	HM	CW	SC	AW	SH	SB	HM
Araneida	X						X														X	X						X		X
Odonata											X								X						X					
Orthoptera	X		X				X								X	X			X	X	X		X		X	X	X	X	X	X
Hemiptera	X			X			X	X					X			X		X	X			X			X			X		
Homoptera	X		X						X			X	X					X	X	X	X				X					
Cicadidae																			X	X		X	X		X	X		X	X	
Cicadellidae	X	X		X			X	X					X	X					X	X		X	X		X			X		
Neuroptera													X												X					
Coleoptera	X			X			X						X						X					X	X				X	
Lepidoptera	X											X						X				X		X	X					X
Diptera	X			X					X				X						X						X	X				
Hymenoptera	X												X	X				X	X						X			X		

[a]Other taxa recorded were Acarina, Ephemeroptera, Isoptera, Plecoptera, Psocoptera, Thysanoptera, and Trichoptera.

Table 30. Cicada counts in riparian habitats on the lower Colorado River, 1982 and 1983. Counts were conducted weekly on established routes through each habitat. Counts were based on the total number of exuvia throughout the summer months, which reflect the number of cicadas emerging in each respective habitat.

Plant community	Hectares surveyed	Cicadas/ha (± SD)
Saltcedar	2.0	23,303 (± 8,886)
Saltcedar-honey mesquite mix	2.0	13,093 (±16,328)
Saltcedar (burned)	2.0	6,853 (± 4,547)
Screwbean mesquite-saltcedar mix	2.0	4,753 (± 7,559)
Cottonwood-willow	2.0	2,351 (± 1,289)

Table 31. Cicada-eating birds before and after burning of a 30-ha saltcedar stand. Bird data from June through August, 1982 and 1983, at Cibola National Wildlife Refuge.

	Year		
Bird category	1981 (preburn)	1982	1983
Total density	150	229	173
Total species richness	15	19	18
Cicada-eater density	84	195	148
Cicada-eater species richness	9	15	15
Percent cicada eaters	56	85	86

Economically important taxa which are subject to pesticide control include orthopterans, thysanopterans (thrips), hemipterans (adult and larvae; true bugs), homopterans (whiteflies and aphids), coleopterans (primarily beetle larvae), lepidopterans (primarily larvae), and dipterans (primarily larvae). Specifically, cotton is infested with boll weevils (*Anthonomus grandis*; family Curculionidae; order Coleoptera), pink bollworm (*Pectinophora gossypiella*; family Gelechiidae; order Lepidoptera), and tobacco budworm (*Heliothus virescens*; family Noctuidae; order Lepidoptera). Lettuce, other vegetables, and citrus can be severely affected by whiteflies (family Aleyrodidae), aphids (family Aphididae), and scale insects (superfamily Coccoidea). Many grasshopper species can affect grain crops and the larvae of hemipterans, coleopterans, lepidopterans, and dipterans can affect vegetables, citrus, melons, and grain crops. Nonarthropod invertebrate pests are primarily nematode worms (phylum Nematoda) and affect the root systems of many crops.

8.3 SPECIES OF SPECIAL CONCERN

One invertebrate species, MacNeill's sootywing (*Pholisora gracielae*, family Hesperiidae, order Lepidoptera), is presently a candidate species for Federal listing on the lower Colorado River. This skipper is restricted to the lower Colorado River from southern Nevada south to Blythe. Quail bush is the sole host plant for the larvae. Two broods are produced each year in April-May and July to October (Tilden and Smith 1986). The status of the species appears to be stable at present. Known localities for this species include Bennett Wash, Parker Dam, Earp, Needles, Blythe, and the Colorado River Indian Reservation.

CHAPTER 9. ICHTHYOFAUNAL COMMUNITIES

Currently, the health of the fish fauna constitutes one of the greatest concerns among managers and biologists on the lower Colorado River. The original Colorado River ichthyofauna has been studied in an effort to determine factors causing their dramatic declines, to conserve remnant populations, and reestablish populations into historical locations. The recent, largely introduced, ichthyofauna is composed of economically important game species, species to feed game species, and species that were introduced to modify or control some feature of the aquatic system. Much of the research on the present ichthyofauna is geared to maintain and increase game species populations. Also, there is a growing interest in studying the dynamics of a community composed almost entirely of exotic species from widely different points of origin.

Management goals for native versus introduced species are almost always in conflict. In terms of economics and present water management, introduced species are favored over native species. However, the Desert Fishes Council is encouraging management agencies to recognize the importance and biological uniqueness of the native fauna. This chapter summarizes the biology and community dynamics of the native ichthyofauna; the biology and community dynamics of the present ichthyofauna; and, finally, the legal status and prospects for the future for the native ichthyofauna. Most information is drawn from the studies of Minckley (1979) and Marsh and Minckley (1985, 1987).

Thirty-seven species of fish have been recorded from the lower Colorado River (Table 32) (Miller 1952; Minckley 1979). Ten of 11 endemic species are now extirpated or extremely local in distribution. Twenty-six species (all but one are introduced) constitute the present Colorado River ichthyofauna. Sixteen additional species have been recently introduced but are not established or are otherwise considered hypothetical.

There are basically five habitat types used by fish on the lower Colorado River. These are classified as (1) mainstream, (2) backwaters, (3) oxbow lakes, (4) reservoirs, and (5) canals. Natural oxbow lakes no longer form, while reservoirs and canals are habitats that did not exist extensively before the 1900's. In addition, mainstream and backwater habitats have been extensively changed since the early 1900's.

9.1 DISTRIBUTIONS AND GENERAL HABITAT USE BY NATIVE SPECIES

The story of most native species along the Colorado River is one of steady and steep decline, leading eventually to extirpation. Six native species unique to the larger Southwestern rivers, referred to as "big-river" fishes, are now extirpated or are very local in distribution (Minckley 1973). These big-river

Table 32. Primary habitats, distribution, and status of lower Colorado River fish. MS = mainstream; BW = backwater; RE = reservoir; CA = canal; OX = oxbow; N = north (Hoover Dam to Parker Dam); C = central (Parker Dam to Cibola Lake); S = south (Cibola Lake to San Luis); Co = common; U = uncommon; R = rare; E = extirpated; X = present habitat use, distribution, and status, and H = historical status or distribution if different from present.

	Primary habitat(s)					Distribution			Status			
Name	MS	BW	RE	CA	OX	N	C	S	Co	U	R	E
Pacific tenpounder[E] (*Elops affinis*)	X							X			X	
Bonytail chub[E] (*Gila elegans*)	X		X			X	H	H	H		X	
Roundtail (Colorado River) chub (*Gila robusta*)	X							H			H	X
Woundfin[E] (*Plagopterus argentissimus*)	X							H			H	X
Colorado squawfish[E] (*Ptychocheilus lucius*)	X					H	H	H	H			X
Speckled dace[a] (*Rhinichthys osculus*)			X			X						X?
Razorback sucker[V] (*Xyrauchen texanus*)	X		X			X	H	X	H		X	
Flannelmouth sucker (*Catostomus latipinnis*)	X					H		H		H		X
Gila topminnow[bE] (*Poeciliopsis occidentalis*)	X	X			X			X?				X?
Desert pupfish[E] (*Cyprinodon macularius*)		X			X			H		H		X

(Continued)

Table 32. (Continued)

Name	Primary habitat(s)					Distribution			Status			
	MS	BW	RE	CA	OX	N	C	S	Co	U	R	E
Utah sucker[1] (*Catostomus ardens*)			X			X						X?
Striped mullet (*Mugil cephalus*)	X	X						X	X			
Threadfin shad[1] (*Dorosoma petenense*)	X	X	X			X	X	X	X			
Rainbow trout[1] (*Salmo gairdneri*)	X		X			X	X		X			
Carp[1] (*Cyprinus carpio*)	X	X	X	X		X	X	X	X			
Goldfish[1] (*Carassius auratus*)						X	X	X		X		
Golden shiner[1] (*Notemigonus crysoleucus*)						X	X	X		X?		
Red shiner[1] (*Notropis lutrensis*)	X	X	X	X		X	X	X	X			
Fathead minnow[1] (*Pimephales promelas*)		X		X		X		X			X	
Flathead catfish[1] (*Pilodictis olivaris*)	X	X		X			X	X	X			
Channel catfish[1] (*Ictalurus punctatus*)	X		X			X	X	X	X			
Black bullhead[1] (*Ictalurus melas*)						X		X			X	
Yellow bullhead[1] (*Ictalurus natalis*)		X				X	X	X	X			

(Continued)

Table 32. (Continued)

Name	Primary habitat(s)					Distribution			Status			
	MS	BW	RE	CA	OX	N	C	S	Co	U	R	E
Mosquitofish[1] (*Gambusia affinis*)	X	X		X		X	X	X	X			
Sailfin molly[1] (*Poecilia latipinna*)		X		X			X	X	X			
Mexican molly[1] (*Poecilia mexicana*)		X		X				X		X		
Striped bass[1] (*Morone saxatalis*)	X		X			X	X	X	X			
Smallmouth bass[1] (*Micropterus dolomieui*)	X					X	X			X		
Largemouth bass[1] (*Micropterus salmoides*)	X	X	X			X	X	X	X			
Warmouth[1] (*Chaenobryttus gulosus*)		X					X	X		X		
Green sunfish[1] (*Chaenobryttus cyanellus*)		X	X	X		X	X	X	X			
Bluegill[1] (*Lepomis macrochirus*)	X	X	X			X	X	X	X			
Redear sunfish[1] (*Lepomis microlophus*)		X	X			X	X	X	X			
Black crappie[1] (*Pomoxis nigromaculatus*)	X	X	X			X	X	X	X			
Mouthbrooder[1] (*Tilapia mossambica*)	X	X		X				X?	X			

(Continued)

Table 32. (Concluded)

Name	Primary habitat(s)					Distribution			Status			
	MS	BW	RE	CA	OX	N	C	S	Co	U	R	E
Zill's tilapia[I] (*Tilapia zillii*)	X	X		X			X	X		X		
Blue tilapia[I] (*Tilapia aurea*)	X	X		X			X	X	X			

[a]Based on one record from Lake Mohave (Minckley 1979).
[b]Based on specimens on the Gila River near the Colorado confluence.
E = Federal endangered species.
V = Vulnerable species.
I = Introduced species.

fishes also shared several morphological features, apparently, for adaptation to the extremely variable flows of Southwestern rivers. These features included large size, leathery skins, reduced or embedded scales, and sickle-shaped fins. Several species have specialized ridges on their backs or extremely thin caudal peduncles (Minckley et al. 1986).

The bonytail chub (*Gila elegans*), Colorado squawfish, and razorback sucker were the most common and widespread of the big-river fishes along the lower Colorado River and were characteristic of mainstream habitats. All three species exploited conditions in the highly fluctuating levels of the predam river. All three used backwater sloughs, where they frequently spawned and avoided flooding in these marginal habitats.

Reduction in numbers of bonytail chub, Colorado squawfish, and razorback sucker was rapid after the closure of Hoover and Parker Dams in 1935 and 1938, respectively. Actual causes of extirpation remain unknown, although habitat changes and predation on larval native fish by introduced species are strongly suspected. Shoreline and backwater habitats, once exclusively available to the native nonpiscivorous juveniles of suckers and minnows, are now inhabited by predatory mosquitofish (*Gambusia affinis*) and many centrarchid species (Myers 1965; Minckley 1973; Minckley et al. 1977). In addition to the big-river fish, the desert pupfish was also a common species on the Colorado River, at least below the Gila River confluence to the Gulf of Mexico. Extirpation of desert pupfish occurred in the United States soon after the turn of the century. Finally, several native species have been recorded in low numbers or are suspected to have occurred in the river. These species include Gila topminnow (*Poeciliopsis occidentalis*; verified only from the Gila River near the Colorado confluence), woundfin (*Plagopterus argentissimus*), roundtail (Colorado

River) chub (*Gila robusta*), and flannelmouth sucker (*Catostomus latipinnis*); speckled dace (*Rhinichthys osculus*) was also known from one specimen in Lake Mohave (Minckley 1973, 1983).

Two native marine species, the striped mullet and the Pacific tenpounder (*Elops affinis*), generally occur in estuaries, but also were found as young or adults upriver into the United States. The striped mullet still occurs in the southern portions of the valley, and habitat characteristics for this species are treated with other present-day members of the lower Colorado River ichthyofauna. The other marine-spawning species, the Pacific tenpounder, still occurs in the most southern portions of the river valley. Morelos Dam became an effective barrier to upriver dispersal for this species, although it remains common at the mouth of the river in Mexico (Minckley 1979).

9.2 BIOLOGY OF NATIVE SPECIES OF SPECIAL INTEREST

Bonytail Chub

The bonytail chub is adapted to the historically variable flow of the Colorado River. As its common name implies, it has a long and slender ("bony") caudal peduncle. Other morphological features include a streamlined body form with a gently arching predorsal hump, large and sickle-shaped fins, reduced or embedded scales, and relatively small eyes. These features all may be adaptations for a specialized existence in the Colorado River, which historically carried heavy silt loads in the turbid and swift flows characteristic of the river during flood stage (Minckley 1973).

Minckley (1973) cites work by Vanicek and Kramer (1969) on the Green River that these fish were never taken in the swift currents, but rather in eddies and pools. Minckley and Meffe (1987) hypothesized that the unique adaptations of this species, as well as the adaptations of other native big-river fish, are specifically for crossing swift channels and surviving through flood stage by avoiding being flushed downstream. Bonytail chubs feed on drift material, including terrestrial invertebrates and adult aquatic invertebrates (Vanicek 1967; Minckley 1973).

The only documented observation of spawning bonytail chub on the lower Colorado River is from Lake Mohave by Jonez and Sumner (1954 *in* Minckley 1973). Five hundred adult fish were observed in May over a gravel shelf in as much as 9 m (30 ft) of water; each female was accompanied by three to five males and eggs were scattered over the gravel. Larval chub presumably feed along river/lake margins and progressively move into deeper waters as they become larger (Minckley 1973).

Presently, the bonytail chub is only found in Lakes Havasu and Mohave, while it has apparently been extirpated throughout the rest of its historical range. Netted individuals are adults no less than 40 cm (16 inches) and are estimated to be no younger than 32 years (Minckley 1973; Williams et al. 1985). Females in reproductive condition are still found, but no successful reproduction is known to occur at present. Suggested reasons for this species' decline are dam construction, interactions with introduced species, and habitat alteration (Williams et al. 1985).

Roundtail (Colorado River) Chub

The roundtail (Colorado River) chub apparently was never common or widespread on the lower Colorado River mainstem. Minckley (1979) cites two specimens collected in 1973 from Imperial Reservoir that morphologically resemble populations from the Bill Williams River. Stragglers, therefore, may still occasionally occur in the mainstem. The roundtail (Colorado River) chub does not share the strongly unique adaptations of its congeners and is even called the "Verde trout" by fishermen for its superficial resemblance to salmonids. The subspecies in our area, G. r. robusta, does not appear to be in imminent danger. Populations elsewhere, however, have declined, with some subspecies (in Nevada) considered to be endangered or vulnerable (Williams et al. 1985).

Woundfin

The only record for the woundfin on the lower Colorado River is from specimens taken near Yuma at the turn of the century. The woundfin was also found along the Salt River near Tempe, AZ, which suggests a much wider distribution along major rivers than currently found (Minckley 1973). The Virgin River system provides the only remaining natural refugium for this species.

Woundfins in the Virgin River system live in the swift parts of silty streams and avoid clearer waters and quiet pools (Minckley 1973). The flattened vertical surface, thick anterior, and thin posterior of the woundfin are adaptations for living near the bottom of swiftly flowing silty streams. These are all characteristics consistent with a fish occurring in the mainstem Colorado River prior to dams.

Colorado Squawfish

The top aquatic predator of the historical lower Colorado River was the Colorado squawfish (Minckley 1973). The largest of the native fish, this species grew to over 2 m (7 ft) in length and preyed heavily on smaller individuals of other species, as well as its own. The adult body form is somewhat compressed dorsoventrally, with a flattened, elongated head (Minckley 1973).

The decline of the Colorado squawfish throughout its range was precipitous. The species was last reported from the lower Colorado River in 1967. Presently, the species is known to persist primarily along the upper Colorado River from Grand Junction, Colorado, to Lake Powell, Green River, lower Yampa River, and lower San Juan River (Williams et al. 1985).

Before the presence of dams, Colorado squawfish were extremely abundant. Numerous accounts exist on how hundreds of squawfish, along with bonytail chub and razorback sucker, were pitchforked out of irrigation ditches and used for fertilizer (Miller 1961; Minckley 1973; Seethaler 1978). A sharp decline in abundance began during the early 1930's with records for this species scarce after 1949 (Miller 1961). A drought in 1934, concomitant with the completion of Hoover Dam, apparently was a proximate cause for the decline. The relatively rapid disappearance of this species, compared with bonytail chub and especially razorback sucker, indicates its extreme intolerance to drastic human-caused changes.

Colorado squawfish move upstream to spawn. These "runs" may have been critically halted by the construction of Hoover and Parker Dams, thus preventing successful reproduction (Williams et al. 1985). Spawning has been observed in the undammed stretches of the upper Colorado River only since the late 1970's, thus information on spawning requirements is just now being gathered (Tyus et al. 1985; Tyus 1987a).

Foods of larval Colorado squawfish consist of small crustaceans and aquatic dipteran larvae, with increasing numbers of aquatic and terrestrial insects as the fish grow (Minckley 1973). Large adults have been known to take small mammals and birds along with their more staple diet of medium-sized fish. Squawfish is known to be a fair game fish, and there have been proposals that squawfish populations be maintained at scattered locations as a game species, including on the Lower Colorado River (Federal Register, 26 August 1987, see Section 9.5).

Razorback Sucker

The razorback sucker is morphologically a very uniquely shaped catostomid. The sharp keel behind the head may be an adaptation to turbulent rivers, such as found along the historical Colorado River. As with other suckers, this species is flattened ventrally with the mouth also ventrally located.

This sucker is the last of the big-river species to have a relatively large, remnant population on the lower Colorado River. It, like the other big-river species, was abundant in the predam era and was often used as food by both Amerinds and Anglo settlers. Razorback suckers declined with major dams in place, but populations persisted longer than those of either the bonytail chub or Colorado squawfish. The largest population is in Lake Mohave, formed by the last of the major dams (Davis, completed by 1954) on the Colorado River (Minckley 1983). Smaller populations persist in Lake Havasu and Senator Wash Reservoir, with a few individuals occasionally found near Laughlin Lagoon, Parker Strip, and Blythe.

Although all adult razorback suckers captured to date are very old (≥30 years; Minckley 1973), fingerlings have been found at Lake Mohave. No intermediate age classes have been found, which strongly suggests that fingerlings perish soon after hatching. Recent research suggests that the missing age classes are being depredated by introduced species, such as green sunfish (Langhorst 1987a). In addition, reduced nutrient flow may affect the general health of young razorback suckers, making them more susceptible to depredation (Papoulias 1987a,b,c). For a review of larval development in razorback sucker see Minckley and Gustafson (1982).

Naturally produced razorback sucker larvae were abundant in littoral zones of Lake Mohave from mid-January to April (Langhorst 1987a). Larvae over 12 mm (0.5 inches) were placed in an isolated backwater to determine growth and survivorship in a predator-free environment (Langhorst 1987a). This backwater was later breached and invading green sunfish were soon found feeding heavily on the razorback sucker larvae, thus halting this experiment.

Foods of larval razorback sucker in Lake Mohave consisted primarily of the zooplankton Bosima and Daphnia. Diet of adult razorback suckers include algae, dipteran larvae, and planktonic crustaceans (Minckley 1973). The "fuzzy" gill-rakers present in razorback suckers strongly suggest that plankton is evolutionarily the most important and stable food source for this species (Minckley 1973).

Foraging habitats for adults appear to be greater than 1 m (3 ft) deep to 15 m (49 ft) in reservoirs. Benthic substrates used include sand, mud, or gravel. Razorback suckers do have adaptations to withstand strong currents, but testimonials, summarized by Minckley (1973), suggested that large adults remained in eddies and backwaters, avoided the strongest currents when possible, and concentrated in deep holes behind cutbanks or fallen trees.

Flannelmouth Sucker

This catostomid was recorded in the late 1800's in the Yuma area, and below Lakes Mead and Mohave (Minckley 1973). No records exist for this species after the turn of the century. In 1976, 600 adult flannelmouth suckers were transplanted from the Paria River to the Bullhead City area in an attempt to control simuliid larvae; none of these individuals were detected after introduction (Minckley 1979).

Flannelmouth sucker can still be found in good numbers in part of its historical range. Minckley (1973) states that this species does poorly in impoundments, while it is characteristic of strongly flowing streams. This species feeds on both vegetation and benthic invertebrates (Minckley 1973).

Desert Pupfish

The desert pupfish is endemic to the lower Colorado River to include the Salton Sea, lower Gila River, and Rio Sonoyta drainage. It is no longer found along the lower Colorado River in the United States proper. The last natural populations occur in Laguna Salada, in saline pools near the Sierra de los Cocopah Mountains, and in Santa Clara Slough in Mexico. Two small populations remain near the Salton Sea, while several reintroduced populations of the subspecifically distinct Quitobaquito Spring population (C. m. eremus; Miller and Fulman 1987) do exist in Arizona. The species, and the lower Colorado River subspecies, also persists in artificial refugia at a number of locations throughout Arizona and at Dexter National Fish Hatchery in New Mexico.

Historically, desert pupfish habitats on the lower Colorado River included springs, marshes, backwaters, and oxbows, while it avoided the mainstem (Minckley 1973). The only lower Colorado River specimens are from the Gila-Colorado confluence and south toward the Gulf of California. Desert pupfish are well known for their wide tolerance of salinity and high water temperatures in the harsh desert climate. However, desert pupfish are not tolerant of introduced species, especially tilapia and centrarchids, and decline quickly in their presence.

As young, desert pupfish include small crustaceans, plants, and bottom debris in their diet. As pupfish grow older, larger invertebrates are taken, including mosquito larvae (Minckley 1973). In warm, shallow habitats where foods are abundant, sexual maturity may be reached in about six weeks, however, pupfish usually live less than a year in natural populations. Predation by large aquatic beetles, bugs, birds, and small mammals are natural sources of loss to pupfish populations.

Gila Topminnow

The Gila topminnow formerly occurred in the Gila River in the vicinity of Dome Valley, just upstream from the Colorado confluence and may have occurred, at least sporadically, around the Yuma area (Minckley and Deacon 1968). Minckley (1973) cites several papers describing this species as among the commonest fishes in central and southern Arizona in the lower Colorado River basin. Documented declines began by the 1930's and were strongly associated with the introduction of mosquitofish (Minckley 1973; Meffe 1985). Adult mosquitofish are documented to feed extensively on larval Gila topminnows where they co-occur.

The Gila topminnow, if it occurred historically on the Colorado River, probably used backwaters, sloughs, and shallows of the mainstream. Foods for Gila topminnow included detritus, aquatic insect larvae (including mosquitoes), and vegetable material. Among the other native species, desert pupfish is the most closely associated with the Gila topminnow throughout the former's range.

The Gila topminnow is on the Federal endangered species list and is also of high priority for protection by the Arizona Department of Game and Fish. An active reintroduction program has been underway in Arizona and has been successful, as of 1987, in establishing new stable populations (Simons 1987). There are no present plans to reintroduce this species into the Gila-Colorado River confluence area, but there may be possibilities for such action in the future.

9.3 PRESENT ICHTHYOFAUNAL USE OF HABITATS ON THE ENTIRE LOWER RIVER

Distribution and Abundance

Minckley (1979) collected data primarily along the mainstream and backwaters of the lower Colorado River for 18 frequently encountered species and their associated habitats. Since larvae and adults of the same species may use separate habitats, fish were separated, by sampling procedure, into two categories based on age or size (Minckley 1979). Seining and scape nets were used to sample larvae and fish species with small adults. Larger fishes were sampled by gill, trammel, hoop, and fyke nets. Some data were collected in canals, although Minckley (1979) states more work is needed in these habitats.

Numerically, threadfin shad was the dominant small fish species in mainstream habitats (Table 33). Red shiner, mouthbrooder, and mosquitofish were also common in the mainstream. Mosquitofish, threadfin shad, red shiner, and bluegill were the four most common small fish in backwaters. In terms of biomass, threadfin shad were dominant in mainstream habitats, followed by red shiner, largemouth bass, sailfin molly (Poecilia latipinna), and bluegill. Other frequently encountered species in mainstream habitats were mosquitofish and mouthbrooder. Dominance by biomass in backwater habitats was shared among black crappie, goldfish (Carassius auratus), channel catfish, and largemouth bass.

Mainstream habitats included deepwater reservoirs. There were some differences, in terms of dominant species, when reservoirs were separated from the mainstream. Threadfin shad were probably much more abundant in reservoirs than the data indicated (Minckley 1979). They occurred in very high densities in the backwaters they occupied. Underestimates of mosquitofish and mouthbrooders also may have occurred (Minckley 1979).

Among the large fish, the river channel was dominated numerically by striped mullet, threadfin shad, warmouth, mouthbrooder, redear sunfish, bluegill, and black crappie. Backwater habitats were dominated by threadfin shad, striped mullet, and carp. Other large species frequently occurring in backwaters included channel catfish and largemouth bass.

Some large species are not adequately sampled by netting in mainstream habitat. Flathead catfish

Table 33. Rank order of frequency, relative abundance, and biomass (small fish) from Minckley (1979). Collections from mainstream and backwater habitats on the Colorado River. Fish are ranked from high to low values.

Species	Mainstream			Backwaters		
	Frequency of occurrence	Relative abundance	Biomass	Frequency of occurrence	Relative abundance	Biomass
SMALL FISH						
Threadfin shad	7.0	1.0	1.0	9.5	2.0	5.0
Carp	13.0	7.0	7.0	6.5	8.0	6.0
Goldfish	--	--	--	9.5	11.0	2.0
Red shiner	1.0	2.0	2.0	3.0	3.0	7.5
Channel catfish	10.0	12.0	11.5	9.5	12.0	3.0
Yellow bullhead	15.0	14.5	9.5	--	--	--
Mosquitofish	2.0	4.0	8.0	5.0	1.0	11.0
Sailfin molly	6.0	5.0	4.0	12.5	6.0	11.0
Mexican molly	14.0	14.5	14.0	--	--	--
Smallmouth bass	16.5	16.0	16.5	--	--	--
Largemouth bass	4.0	8.0	3.0	2.0	9.0	4.0
Warmouth	16.5	17.0	16.5	12.5	13.0	11.0
Green sunfish	9.0	13.0	9.5	6.5	10.0	14.0
Bluegill	3.0	6.0	5.0	1.0	4.0	7.5
Redear sunfish	8.0	11.0	11.5	9.5	5.0	9.0
Black crappie	11.0	9.0	14.0	4.0	7.0	1.0
Mouthbrooder	5.0	3.0	6.0	--	--	--
Zill's tilapia	12.0	10.0	14.0	--	--	--
LARGE FISH						
Threadfin shad	5.5	2.0	--	1.0	1.0	--
Carp	4.0	10.0	--	2.0	3.0	--
Channel catfish	1.0	8.0	--	3.0	8.5	--
Yellow bullhead	12.5	13.5	--	9.0	4.0	--
Black bullhead	--	--	--	13.5	8.5	--
Flathead catfish	14.5	13.5	--	10.0	12.5	--
Smallmouth bass	12.5	13.5	--	--	--	--
Largemouth bass	7.0	9.0	--	4.0	11.0	--
Warmouth	9.0	3.0	--	--	--	--
Green sunfish	11.0	13.5	--	13.5	14.0	--
Bluegill	2.0	6.5	--	8.0	10.0	--
Redear sunfish	3.0	5.0	--	5.0	6.0	--
Black crappie	10.0	6.5	--	6.0	7.0	--
Striped bass	14.5	--	--	11.5	12.5	--
Mouthbrooder	8.0	4.0	--	11.5	5.0	--
Striped mullet	5.5	1.0	--	7.0	2.0	--

(*Pilodictis olivaris*) are especially undersampled except when electroshocked. Electroshocking was efficient in sampling large numbers of adult flathead catfish in the Yuma area (Marsh and Minckley 1987). Striped bass, another top carnivore, and rainbow trout were also undersampled. Populations for these species are maintained mostly by hatchery stocking (see below for these species' use of habitats).

Canals were sampled in the Yuma Valley by seining and through application of pesticides. Relative numbers of fish were dominated by red shiner, mosquitofish, sailfin molly, threadfin shad, and mouthbrooder in descending order (Table 34). Poisoning produced about three times the fish sampled by seining, although relative abundances, except for mosquitofish, did not change dramatically.

Recent Changes in Status Among Introduced Species

Three economically important species have changed in status on the lower Colorado River since 1976. Striped bass is a commercially important game species that has become more widespread along the river but has also declined in areas of previous abundance. In addition, a new species of tilapia has appeared on the Colorado River, while another species has disappeared since 1976. Some life-history characteristics for each species, in relation to status changes are discussed below.

Striped bass were introduced near Blythe in 1959 and elsewhere on the river at various times in the 1960's and 1970's (Table 35) (Minckley 1973; Grabowski et al. 1984). Reproduction of striped bass on the lower Colorado River has never been extensive. Striped bass are anadromous and may require long stretches of flowing water to spawn. Spawning runs were noted near the Palo Verde Weir in May 1964 and again in 1965. Natural recruitment has always been hampered by wave action carrying the semi-bouyant eggs to shore or covering them with sediment (Edwards 1974; Minckley 1979).

Table 34. Relative abundance (in percent) of all fishes taken by seines and by pesticide in canals of Yuma Valley, Limitrophe Division, lower Colorado River, summer 1974. tr = trace. From Minckley (1979).

Species	Seines	Pesticide	Species	Seines	Pesticide
Threadfin shad	4.0	8.6	Sailfin molly	16.5	9.4
Red shiner	36.7	35.5	Mexican molly	--	tr
Carp	3.4	0.7	Largemouth bass	2.7	0.3
Channel catfish	1.7	1.1	Bluegill	3.9	0.9
Yellow bullhead	0.1	0.1	Redear sunfish	0.1	tr
Flathead catfish	--	0.2	Green sunfish	0.1	0.4
Mosquitofish	19.4	35.2	Mouthbrooder	10.6	7.7

Total fish captured: Seines 9,940 Pesticides 32,400

Table 35. Stocking records for striped bass on the lower Colorado River. Adapted from Grabowski et al. (1984).

Year	Location	Number	Agency
1959	Blythe	1,000	California Department of Fish and Game
	Ferguson Lake	590	California Department of Fish and Game
1961	Blythe	1,737	California Department of Fish and Game
	Martinez Lake	1,500	California Department of Fish and Game
1962	Topock	17,200	California Department of Fish and Game
	Davis Dam	25,000	California Department of Fish and Game
	Needles	38,205	California Department of Fish and Game
1963	Topock Gorge	41,476	California Department of Fish and Game
	Blythe	20,000	United States Fish and Wildlife Service and California Department of Fish and Game
1964	Topock Gorge	15,100	California Department of Fish and Game
	Topock	9,421	California Department of Fish and Game
1969	Lake Mead	20,000	Nevada Department of Wildlife
	Colorado River	9,145	Arizona Department of Game and Fish
1970	Lake Mead	16,300	Nevada Department of Wildlife
1971	Lake Mead	1,034	Nevada Department of Wildlife
1972	Lake Mead	3,000	Arizona Department of Game and Fish

With recruitment already low, striped bass have declined, with individuals over 9 kg (20 lb) now rare, whereas they were common during the 1970's (Burrell 1987). In addition, a major food item for striped bass is stocked rainbow trout, which are no longer maintaining stable populations in the Bullhead City-Laughlin area due to simuliid control programs. Striped bass may be overeating their food bases in these areas, but much more work is needed to confirm these trends (Minckley 1973; Giusti and Milliron 1987). Concomitant with declines in the north valley, there was a temporary increase of striped bass in the Yuma area during the flood of 1983-84 (Marsh and Minckley 1985, 1987).

The second major change in status involves the exchange in dominance of two tilapia species. During Minckley's (1979) study, two species of tilapia were found. Mouthbrooder and Zill's tilapia (*Tilapia zillii*) were restricted to south of Imperial Dam. Mouthbrooders were common as adults in both mainstream and backwater habitats and as young in the mainstream, while Zill's tilapia were never numerous. By 1985, the blue tilapia (*Tilapia aurea*) was the only common tilapia captured in the Yuma Division, with the mouthbrooder completely absent. Zill's tilapia presently remains uncommon to rare and is reported from south of Parker Dam; however, the majority of records are south of Palo Verde Diversion Dam.

Initial introductions of tilapia into the lower Colorado River were presumably of mouthbrooder in the Yuma Canal in 1963 (Table 36). Introductions were made in the hope of biological control of aquatic vegetation, to provide a food source for larger fish, and to possibly provide a new fishery (Grabowski et al. 1984). Stocking on the lower Colorado River continued until the mid-1970's, with identified fish primarily being mouthbrooder. Unauthorized stocking activities and bait-fish releases have also been widespread and have involved many different species or strains. About eight tilapia species and hybrids were present or suspected in the lower Colorado River system by 1983 (Barrett 1983; Grabowski et al. 1984). The blue tilapia has become the common dominant species, while the mouthbrooder has all but disappeared from the Yuma Division. A greater tolerance of colder water and the aggressive and competitive nature of blue tilapia are often cited as causes for this response, although no pertinent studies have been conducted to verify these factors (Grabowski et al. 1984). Overall, tilapia have provided an additional fishery in the southern valley, but interference with largemouth bass spawning may negate any positive aspects that these species may have (Marsh and Minckley 1985). The effectiveness of tilapia as an herbivore in reducing aquatic vegetation in canals has been equivocal.

Table 36. Stocking records for tilapia on the lower Colorado River. Adapted from Grabowski et al. (1984).

Year	Location	Species	Number	Source
1963	Yuma Canal	*Tilapia* (sp.)	400	?
1965	Riverside Park-Yuma	*Tilapia* (sp.)	700	Page Springs
1971	Imperial Valley	*Tilapia* (sp.)	7,233	Salinity Canal
	Palo Verde Valley	*Tilapia* (sp.)	2,259	Salinity Canal
	Quechan Indian Reservation	*Tilapia* (sp.)	3,600	Salinity Canal
1975	Mittry Lake	*T. mossambica*	3,207	Sally Ann No. 1
1976	Yuma City A-Canal Water Monitor	*T. mossambica*	2,500	Yuma Canal
	B-Canal	*T. mossambica*	34	Yuma Canal

9.4 HABITAT RELATIONSHIPS ON THE ENTIRE LOWER RIVER AMONG INTRODUCED SPECIES

Methods

Most seining samples from the mainstream (Minckley 1979) were in linear versus eddying currents, over mud or over sand bottoms, and at depths ranging from <0.5 m (<1.6 ft) to about 2.5 m (8.2 ft). In addition, most seining was along unmodified banks, in areas of no vegetation or submergent macrophytes, and in the general absence of cover other than aquatic vegetation. In particular, where currents typically were absent or eddying, waters that were sampled tended to be deep, bottoms were of mud or sand, banks were unmodified, higher plants were absent or present in the submergent state, and cover again was minimal.

Gill, trammel, and hoop net sets in the mainstream sampled moving water over coarser (gravel) bottom types (Minckley 1979). Nets were set in water from <1.0 m (<3.3 ft) to 18 m (59 ft) deep adjacent to emergent wetlands and unmodified (both cut and uncut) and modified banks. Sampling areas were about equally divided between banks supporting larger plants and those that were barren or covered with algae. Most sites lacked cover other than aquatic plants. Backwaters where nets were set were mostly slow-moving with mud or silt bottoms, <1.0 to 12 m (<3.3 to 39.4 ft) deep, and with marshy or uncut banks. Most backwaters had substantial vegetative cover. Cover other than vegetation (e.g., undercut bank) was essentially absent in backwaters.

Habitat descriptors included criteria describing mainstream (including reservoirs) and backwater: (1) current types (none, eddying, and linear); (2) current velocity (none, >0-0.5 m/sec [>1.6 ft/sec], 0.5-1.0 m/sec [1.6-3.3 ft/sec], and >1.0 m/sec [>3.3 ft/sec]); (3) bottom type (mud, silt, sand, gravel, and boulder); (4) depth (<0.5 m [<1.6 ft], 0.5-1.0 m [1.6-3.3 ft], 1.0-2.0 m [3.3-6.6 ft], >2.0 m [>6.6 ft]); (5) bank types (marsh, unmodified, modified); (6) vegetation present (none, algae, submerged macrophytes, emergents); and (7) cover (none, submerged debris, undercut bank, and riparian plants). Habitat characteristics for each fish species are summarized in Table 37a,b.

Results

Most small fish tended to avoid currents in the mainstream. Species using currents with linear flow included red shiner, sailfin molly, black crappie, and both species of tilapia (Table 37a,b). In backwaters, red shiner and channel catfish were found in eddying currents, while the other small fish remained in areas of no currents. Most centrarchids avoid-currents, however, some green sunfish, largemouth bass, and most black crappie were found in currents of <0.5 m/sec (<1.6 ft/sec).

Detritivorous species (including mouthbrooder, sailfin molly, Zill's tilapia, mosquitofish, and threadfin shad) occurred on organic mud substrates. Red shiner and channel catfish were associated with silt or sand substrates. Carp, largemouth bass, and smaller centrarchids avoided mud substrates. Overall, gravel was not an important substrate for small fishes.

Most small fishes were associated with uncut and unmodified banks along the lower Colorado River. However, red shiner, channel catfish, sailfin molly, and green sunfish more often were found in open water near cut banks. Black crappie and mouthbrooder were associated with banks bordered by

Table 37a. Habitat characteristics for fish on the lower Colorado River in mainstream and backwater habitats. N = none, E = eddying, L = linear, M = mud, Si = silt, Sa = sand, G = gravel, B = boulders. Data from Minckley (1979).

	Current type			Current velocity (m/sec)			Bottom type					Depth (m)			
Size/species/ habitat	N	E	L	N	0.0-0.5	0.5+	M	Si	Sa	G	B	<0.5	0.5-1.0	1.0-2.0	>2.0
SMALL FISH															
Threadfin shad															
Mainstream	X			X					X			X			
Backwater	X			X			X						X		
Carp															
Mainstream	X			X				X				X			
Backwater	X			X				X					X		
Goldfish															
Mainstream[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Backwater		X			X		X						X		
Red shiner															
Mainstream			X		X			X	X			X			
Backwater		X			X			X	X			X			
Channel catfish															
Mainstream	X			X				X				X			
Backwater		X			X				X			X			
Yellow bullhead															
Mainstream	X			X				X				X			
Backwater[a]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Mosquitofish															
Mainstream	X		X	X	X		X	X				X			
Backwater	X	X		X	X		X					X			
Sailfin molly															
Mainstream			X		X		X					X			
Backwater	X			X			X						X		
Largemouth bass															
Mainstream	X			X				X				X			
Backwater	X			X				X					X		
Green sunfish															
Mainstream	X			X	X			X				X			
Backwater	X			X					X			X			
Bluegill															
Mainstream	X			X				X	X			X			
Backwater	X			X			X		X			X			

(Continued)

Table 37a. (Continued)

Size/species/ habitat	Current type N	E	L	Current velocity (m/sec) N	0.0–0.5	0.5+	Bottom type M	Si	Sa	G	B	Depth (m) <0.5	0.5–1.0	1.0–2.0	>2.0
SMALL FISH (Cont.)															
Redear sunfish															
Mainstream	X			X				X				X			
Backwater	X			X			X							X	
Black crappie															
Mainstream			X		X			X				X			
Backwater	X			X			X					X	X		
Mouthbrooder															
Mainstream			X		X		X					X			
Backwater[a]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Zill's tilapia															
Mainstream			X		X		X					X			
Backwater[a]	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
LARGE FISH															
Threadfin shad															
Mainstream	X			X			X								X
Backwater	X			X			X							X	
Carp															
Mainstream			X		X				X	X				X	
Backwater	X			X			X								X
Channel catfish															
Mainstream			X		X				X	X				X	X
Backwater	X			X			X								X
Yellow bullhead															
Mainstream	X	X	X		X		X							X	
Backwater	X			X			X							X	
Flathead catfish															
Mainstream			X		X		X								X
Backwater	X			X			X								X
Largemouth bass															
Mainstream			X		X				X	X				X	
Backwater	X			X			X								X

(Continued)

Table 37a. (Concluded)

Size/species/ habitat	Current type			Current velocity (m/sec)			Bottom type					Depth (m)			
	N	E	L	N	0.0-0.5	0.5+	M	Sl	Sa	G	B	<0.5	0.5-1.0	1.0-2.0	>2.0
LARGE FISH (Cont.)															
Bluegill															
Mainstream			X		X				X	X					X
Backwater	X			X			X						X	X	
Redear sunfish															
Mainstream				X	X	X[b]				X	X				X
Backwater	X		X				X						X		
Black crappie															
Mainstream			X			X			X						X
Backwater	X			X			X								X
Striped bass															
Mainstream		X				X		X							X
Backwater	X			X			X						X		
Mouthbrooder															
Mainstream	X			X			X							X	
Backwater	X			X			X							X	
Striped mullet															
Mainstream			X		X		X							X	
Backwater	X			X			X							X	

[a]Sample sizes <10.
[b]Over 1 m/sec.

Table 37b. Ma = marsh (emergent vegetation), U = unmodified, N = none, Al = algae, Sub = submergent, Em = emergent, SubD = submerged debris, UCB undercut bank, Rip = woody riparian. Cover is other than aquatic vegetation.

	Bank			Vegetation				Cover			
Species	Ma	U	Mo	N	Al	Sub	Em	N	SubD	UCB	Rip
SMALL FISH											
Threadfin shad											
Mainstream		X		X				X			
Backwater		X				X		X			
Carp											
Mainstream		X			X			X			
Backwater		X				X		X			
Goldfish											
Mainstream[a]	-	-	-	-	-	-	-	-	-	-	-
Backwater		X				X					X
Red shiner											
Mainstream		X		X	X	X	X	X			
Backwater		X				X		X	X		X[b]
Channel catfish											
Mainstream		X			X				X		
Backwater		X			X			X			
Yellow bullhead											
Mainstream		X			X			X			
Backwater[a]	-	-	-	-	-	-	-	-	-	-	-
Mosquitofish											
Mainstream		X			X			X			
Backwater		X				X		X			
Sailfin molly											
Mainstream		X		X				X			
Backwater		X				X		X			
Largemouth bass											
Mainstream		X			X			X			
Backwater		X				X		X			
Green sunfish											
Mainstream		X			X			X			
Backwater		X				X		X			
Bluegill											
Mainstream		X		X				X			
Backwater		X				X		X			
Redear sunfish											
Mainstream		X			X			X			
Backwater		X				X		X			

(Continued)

Table 37b. (Continued)

	Bank			Vegetation				Cover			
Species	Ma	U	Mo	N	Al	Sub	Em	N	SubD	UCB	Rip
Black crappie											
Mainstream	X	X			X			X			
Backwater	X	X				X		X			
Mouthbrooder											
Mainstream	X				X			X			
Backwater[a]	-	-	-	-	-	-	-	-	-	-	-
Zill's tilapia											
Mainstream			X			X		X			
Backwater[a]	-	-	-	-	-	-	-	-	-	-	-
LARGE FISH											
Threadfin shad											
Mainstream		X		X				X			
Backwater		X		X				X			
Carp											
Mainstream		X				X		X			X[b]
Backwater	X					X		X			
Channel catfish											
Mainstream		X				X		X			X[b]
Backwater	X					X		X			
Flathead catfish											
Mainstream		X		X				X			
Backwater	X			X				X			
Largemouth bass											
Mainstream			X	X				X			X[b]
Backwater		X		X				X			
Bluegill											
Mainstream		X		X				X			
Backwater	X					X		X			
Redear sunfish											
Mainstream		X			X			X			
Backwater		X				X		X			
Black crappie											
Mainstream	X			X				X			
Backwater	X			X				X			
Striped bass											
Mainstream		X		X				X			
Backwater		X				X		X			
Mouthbrooder											
Mainstream	X					X		X			X[b]
Backwater	X					X		X			

(Continued)

Table 37b. (Concluded)

Species	Bank			Vegetation				Cover			
	Ma	U	Mo	N	Al	Sub	Em	N	SubD	UCB	Rip
LARGE FISH (Cont.)											
Striped mullet											
Mainstream		X				X		X			
Backwater	X					X		X			

[a]Sample size <10.
[b]Some preference for this cover type exhibited (Minckley 1979).

emergent wetland. The avoidance of cut or modified banks may be related to the lack of shallow waters favored by most small fish.

Most large fish in the mainstream were associated with linear flows of at least 0.5 m/sec (1.6 ft/sec). Exceptions were threadfin shad and mouthbrooder (occurred where no current was detectable), striped bass (occurred with eddying current), and yellow bullhead (occurred equally often in areas of eddying, linear, or no current). In backwaters, all larger fish were most often associated with no current.

Carp, channel catfish, largemouth bass, bluegill, redear sunfish, and black crappie were most closely associated with sand or gravel substrates in the mainstream. In addition, redear sunfish were often found in areas with boulder bottoms, which were indicative of swifter flows. The other large fish were most often found in the mainstream on mud or silt (flathead catfish and striped bass) substrates. All large fish in backwaters were most often encountered in areas with mud substrates. Most large fish were found at depths of at least 1 to 2 m (3.3 to 6.6 ft). However, bluegill, redear sunfish, and striped bass occurred between 0.5 and 1 m (1.6 and 3.3 ft) in backwaters. On the other extreme, threadfin shad and mouthbrooder usually were found over mud bottoms in deep, calm areas.

Largemouth bass were the only fish associated with modified banks in deeper waters. All other large fish tended to avoid modified banks. A number of large fishes were associated with areas bordered by marshes. Bluegill and striped mullet were in backwaters and black crappie and mouthbrooder were in both mainstream and backwaters.

Carp, channel catfish, yellow bullhead, mouthbrooder, and striped mullet were associated with beds of submergent aquatic vegetation in the mainstream. In addition, bluegill, redear sunfish, and striped bass were found in these beds in backwaters. Cover other than aquatic plants was generally unused. However, carp, red shiner, channel catfish, largemouth bass, and mouthbrooder were disproportionately common where riparian vegetation provided cover along the shoreline (Minckley 1979).

9.5 INTERACTIONS AND FOOD OF PRESENT ICHTHYOFAUNA

The lower Colorado River ichthyofauna consists of a group of species able to occupy a variety of habitats, despite a narrow food base (Minckley 1979, 1982; Marsh and Minckley 1987). Each species uses a special assemblage or point source of foods, with carnivores having a broader spectrum of available food than species at lower trophic levels. Species such as redear sunfish were introduced as forage for game fishes; however, it was the introduction of threadfin shad that increased the growth rates of piscivorous fishes. Increasing demands for additional sports fish resulted in the introduction of striped bass. Striped bass and flathead catfish are voracious piscivores and may outstrip local forage bases (Minckley 1973; Edwards 1974; Burrell 1987). Striped bass, in particular, feed heavily on rainbow trout in Lake Mohave (Grabowski et al. 1984).

The present ichthyofauna of the lower Colorado River may be developing patterns of community structure analogous to that found in natural systems (Minckley 1979, 1982; Marsh and Minckley 1987). Trophically, detritivorous species include threadfin shad, goldfish, carp, all tilapia, and striped mullet (Table 38a,b) (Minckley 1982). Red shiner, sailfin molly, and yellow bullhead also take in large quantities of detritus. Pieces of aquatic macrophytes make up most of the identifiable material in stomachs of detritivores (Minckley 1979). High incidence of Asiatic clams in carp and catfish indicates possible use of this mollusc's pseudofeces (excess edible materials passed through _Corbicula_'s siphons).

Herbivores in the lower Colorado River presently graze on aquatic plants in the mainstream, backwaters, and canals. Vegetative materials make up at least a part of the diet for all lower Colorado River fishes except centrarchids. Channel catfish and tilapia are considered facultative herbivores. Juvenile black crappie are considered planktivores.

Insectivores constitute the largest foraging guild on the lower Colorado River and include all centrarchids, cyprinids, salmonids, and catostomids. Chironomids are, by volume, the most often consumed benthic invertebrates and are found in the diets of all fish species. Hydropsychid caddisflies are also important food items, especially for rainbow trout. Infestations of these trichopterans have resulted in the reintroduction of the native razorback sucker in the Parker area in the clams and crayfish taken by piscivores and smallmouth bass.

Piscivores include channel and flathead catfish, largemouth bass, and striped bass. These species feed primarily on threadfin shad, red shiner, and the young of most other fish species. These are the top aquatic consumers in the Colorado system today, having replaced the Colorado squawfish.

Overall for the system, detritivory is most prevalent in the lowermost portion of the Colorado River. Detritivores are primarily constrained by cold winter temperatures characteristic of the upper reaches, and by distance from marine conditions for the striped mullet. However, the detrital food base is broader in the downstream portions because of accumulations of material coming from

Table 38a. Summary of frequency of occurrence of various food items in stomachs of large fish from the lower Colorado River, 1974-1976, as percentages of all stomachs examined for each species. From Minckley (1982).

Items in stomachs	Rainbow trout	Common carp	Channel catfish	Flathead catfish	Yellow bullhead	Smallmouth bass	Largemouth bass	Striped bass	Striped mullet
Number of stomachs	38.0	135.0	137.0	16.0	23.0	27.0	189.0	100.0	21.0
Total length,									
limits in mm	152.0-440.0	175.0-864.0	236.0-737.0	93.0-325.0	178.0-813.0	118.0-432.0	99.0-560.0	540.0-893.0	381.0-495.0
Percentage empty	18.4	7.8	16.1	12.5	39.1	29.6	11.6	45.0	0.0
Inorganic materials									
Sand, gravel, etc.	--	30.4	--	--	--	--	3.7	--	95.2
Vegetative materials									
Detritus	--	42.2	32.9	12.5	--	--	--	--	100.0
Macrophytes	2.6	1.5	40.9	18.8	--	--	--	--	4.8
Benthic and									
epiphytic algae	42.1	3.7	8.0	--	--	--	--	--	14.3
Phytoplankton	--	33.3	0.7	--	--	--	--	--	14.3
Animal materials									
Crustacea	34.3	7.4	24.8	56.3	26.1	29.6	15.3	7.0	--
Copepoda	29.0	0.7	--	--	--	--	10.6	--	--
Cladocera	5.3	3.0	--	--	--	--	4.8	--	--
Ostracoda	--	0.7	--	--	--	--	1.6	--	--
Decapoda									
Astacidae	5.3	3.7	21.2	56.3	26.1	29.6	3.7	7.0	--
Paleomoneidae	--	--	3.7	--	--	--	8.5	--	--
Benthic Insecta	26.3	33.3	5.1	37.5	8.7	29.6	9.0	--	4.8
Ephemeroptera	--	1.5	--	--	--	29.6	--	--	--
Odonata									
Zygoptera	--	--	--	--	--	--	2.1	--	--
Anisoptera	--	0.7	--	--	8.7	--	1.6	--	--
Megaloptera	--	--	--	--	--	11.1	--	--	--

(Continued)

Table 38a. (Continued)

Items in stomachs	Rainbow trout	Common carp	Channel catfish	Flathead catfish	Yellow bullhead	Smallmouth bass	Largemouth bass	Striped bass	Striped mullet
Trichoptera	18.4	3.0	--	--	4.4	3.7	0.5	--	--
Diptera									
Tipulidae	--	0.7	--	--	4.4	--	--	--	--
Culicidae	--	--	--	6.2	--	--	--	--	--
Simuliidae	23.7	--	--	--	--	3.7	--	--	--
Chironomidae	26.3	33.3	5.1	37.5	--	3.7	9.0	--	4.8
Undetermined taxa	2.6	2.2	--	--	--	--	--	--	--
Mollusca	--	46.7	29.2	6.3	--	--	1.6	--	--
Sphaeriidae	--	46.7	29.2	6.3	--	--	1.6	--	--
Oligochaeta	--	6.7	1.5	37.5	--	--	--	--	--
Vertebrata	34.2	2.2	19.7	--	43.5	11.1	55.0	51.0	--
Salmonidae									
Salmo gairdneri	--	--	--	--	--	--	--	13.0	--
Clupeidae									
Dorosoma petenense	34.2	2.2	5.1	--	4.3	--	53.4	35.0	--
Cyprinidae									
Cyprinus carpio	--	--	--	--	4.3	--	--	1.0	--
Notropis lutrensis	--	1.4	7.3	--	13.0	3.7	7.9	--	--
Ictaluridae									
Ictalurus punctatus	--	--	--	--	4.3	--	--	--	--
Centrarchidae									
Micropterus salmoides	--	--	--	--	--	--	0.5	3.0	--
Lepomis cyanellus	--	--	--	--	--	--	--	1.0	--
Undetermined species	--	--	2.9	--	4.3	7.4	1.6	--	--

(Continued)

Table 38a. (Concluded)

Items in stomachs	Rainbow trout	Common carp	Channel catfish	Flathead catfish	Yellow bullhead	Smallmouth bass	Largemouth bass	Striped bass	Striped mullet
Undetermined fishes	--	--	3.6	--	--	--	1.1	--	--
Ambystomatidae									
Ambystoma tigrinum	--	--	0.7	--	--	--	--	2.0	--
Undetermined vertebrates (?)	--	--	--	--	--	--	--	6.0	--

Table 38b. Summary of frequency of occurrence of various food items in stomachs of small- and medium-sized fish from the lower Colorado River, 1974-1976, as percentages of all stomachs examined for each species. From Minckley (1982).

Items in stomachs	Threadfin shad	Red shiner	Mosquitofish	Sailfin molly	War-mouth	Green sunfish	Bluegill	Redear sunfish	Black crappie	Mouth-brooder
Number of stomachs	49.0	79.0	42.0	52.0	16.0	51.0	47.0	34.0	29.0	65.0
Total length, limits in mm	37.0-193.0	33.0-56.0	21.0-37.0	27.0-64.0	82.0-155.0	75.0-205.0	78.0-213.0	85.0-305.0	173.0-327.0	95.0-289.0
Percentage empty	0.0	11.4	2.4	0.0	31.3	31.6	0.0	5.9	0.0	0.0
Organic materials										
Sand, gravel, etc.	81.8	3.8	2.4	19.4	12.5	2.0	2.1	8.8	--	20.0
Vegetative materials										
Detritus	98.0	62.0	--	100.0	--	--	--	--	--	63.1
Macrophytes	--	--	--	--	--	--	--	--	41.4	44.6
Benthic and epiphytic algae	16.3	2.5	54.8	82.7	--	--	--	5.9	--	27.7
Phytoplankton	16.3	--	--	--	--	--	--	--	--	--
Animal materials										
Crustacea	20.4	26.6	--	--	--	7.8	63.8	--	10.3	--
Copepoda	20.4	21.5	--	--	--	7.8	51.1	--	6.9	--
Cladocera	4.1	11.4	--	--	--	--	19.1	--	3.4	--
Ostracoda	--	--	--	--	--	2.0	--	--	3.4	--
Decapoda										
Astacidae	--	--	--	--	12.5	3.9	--	--	6.9	--
Paleomoneidae	--	--	--	--	6.2	7.8	--	--	41.4	--
Benthic Insecta	26.5	24.1	61.9	--	43.8	35.3	46.8	8.8	--	16.9
Ephemeroptera	--	3.8	--	--	--	--	--	--	--	--
Odonata										
Zygoptera	--	--	--	--	31.2	9.8	--	--	--	1.5
Anisoptera	--	--	--	--	12.5	5.8	--	--	--	--

(Continued)

Table 38b. (Concluded)

Items in stomachs	Threadfin shad	Red shiner	Mosquitofish	Sailfin molly	War-mouth	Green sunfish	Bluegill	Redear sunfish	Black crappie	Mouth-brooder
Trichoptera	--	1.3	--	--	--	--	--	--	--	--
Diptera										
Culicidae	--	--	42.5	--	--	2.0	4.2	--	--	--
Simuliidae	4.1	--	--	--	--	--	--	--	--	--
Chironomidae	--	24.1	9.5	--	6.2	35.3	46.8	8.8	--	16.9
Dixidae (?)	--	--	26.2	--	--	--	2.1	--	--	--
Undeter. taxa	4.1	5.1	19.0	--	--	--	8.5	--	--	1.5
Terrestrial invertebrates	--	--	42.9	--	12.5	9.8	2.1	--	--	3.1
Hymenoptera										
Formicidae	--	--	16.7	--	12.5	3.9	--	--	--	--
Homoptera										
Aphididae	--	--	9.5	--	--	--	--	--	--	--
Araneida										
Undeter. taxa	--	--	--	--	--	7.8	--	--	--	--
Mollusca	--	--	--	--	--	--	--	58.8	--	26.2
Sphaeriidae	--	--	--	--	--	--	--	55.9	--	23.1
Physidae	--	--	--	--	--	--	--	5.9	--	3.1
Oligochaeta	--	3.8	--	--	--	--	--	--	--	1.5
Verterbrata	--	--	--	--	25.0	5.8	--	2.9	55.2	--
Clupeidae										
Dorosoma petenense	--	--	--	--	--	--	--	2.9	20.7	--
Cyprinidae										
Cyprinus carpio	--	--	--	--	--	3.9	--	--	--	--
Poeciliidae										
Gambusia affinis	--	--	--	--	18.8	--	--	--	--	--
Undeter. species	--	--	--	--	--	2.0	--	--	--	--
Undeter. fishes	--	--	--	--	--	2.0	--	--	--	--

upstream and diminution of flow as a function of human use (Minckley 1979, 1982).

The aquatic food web of the lower Colorado River is controlled by water flow regimes and introductions of exotic invertebrates and fish. Organic transport through the system is stopped by dams, except the downstream movement of plankton and microdebris. The debris and nutrients not cropped by fish in upstream impoundments form the food base for the lower reaches of the lower Colorado River. Productivity in the mainstream is enhanced somewhat by additional nutrients from irrigation return flow. This narrow, detritus-based trophic system has become established with the high insolation of the system. In addition, invertebrate and introduced fish species depend on the detritus of primary producers. These food items pass through second-order fish consumers and then to the large piscivores. Finally, large fishes that are not typically piscivorous feed directly on detritus or plant-dependent clams and crayfish.

9.6 PARKER II AND YUMA DIVISION STUDIES

Aquatic studies conducted by Minckley (1979; discussed above) in the mid-1970's along the entire lower Colorado River provided an extensive baseline data set to which other studies may be compared. Two more specific and local aquatic studies were undertaken in the mid-1980's. The goals of these two studies were slightly different, but both were conducted with similar techniques to address potential effects on the present ichthyofauna from bankline and channel modifications. Both studies overlapped the very high flow years (1983-1986), possibly confounding interpretation of results for application to "normal" flow years and comparisons with Minckley's (1979) study. Comparisons between the more recent studies and Minckley's (1979) study for large fish (especially flathead catfish and striped bass) also may be complicated due to the use of electrofishing techniques only in the former studies.

Parker II Division

The purpose of the Parker II Division study was to assess aquatic resources in association with various bankline situations (Hiebert and Grabowski 1987). Proposals to stabilize banks with riprap and channelize extensive portions of the river in the Parker II Division necessitated very specific data for planning operations in minimizing impacts and outlining criteria for mitigation. Data were collected from October 1983 through August 1985, which extensively overlapped the high-flow years.

Seven bankline habitats were identified: riprap, cutbank, cattail, rootwads, Poston Wasteway, shallow channel, and mixed. Riprap included areas where boulders were already in place. Cutbanks were nearly perpendicular walls, including those undercut with no beaches and those which were cut, but had sloped beaches or sand banks adjacent to them. "Cattail" included areas where the bankline was covered with emergent vegetation. "Rootwads" were areas where a combination of overhanging riparian roots and submergent vegetation were found along the bankline. Poston Wasteway was a unique area in being the only confluence where water flow was sluggish and not unlike a backwater situation. Shallow channel included areas with low water depth with, usually, substrates consisting of sand or *Corbicula* shells. Mixed habitats were areas with miscellaneous combinations of the other habitats.

Fluctuations and variations in physicochemical properties of the Parker II Division in 1983-1985 did not differ markedly from previous studies (Minckley 1979; Hiebert and Grabowski 1987). High water flows may have further reduced biomass productivity more than would have been expected but not severely so. Submergent vegetation was severely reduced, however, and may have affected cover and potential foraging sites for larval fish. Future studies are needed to confirm these possibilities.

Rootwad, cutbank, and cattail habitats, in sequential order, were the most important habitats to fish in terms of total abundance and to the majority of species present (Table 39). Riprap and mixed habitats were clearly the worst for fish. Cover supplied by overhanging riparian, emergent, and submergent vegetation was very important to most fish species, as apparently were undercut banks (Hiebert and Grabowski 1987). Despite the overall low occurrence of fish in riprap, this was an important habitat to smallmouth bass. Lastly, the Poston Wasteway was not important overall to fish in the Parker II Division, but apparently provided a winter refugium (especially for Zill's tilapia) as well as a source of nutrients for the river from irrigation runoff (Hiebert and Grabowski 1987).

Bluegill, carp, largemouth bass, and red shiner were numerically the most abundant and widespread species (Table 40). Gill netting was by far the most productive sampling technique, followed by seining. As mentioned earlier, seining was the best sampling technique for small fish. Electrofishing did not produce results radically different for large fish from hoop netting, except for threadfin shad.

Overall, the ichthyofaunal community of the Parker II Division was dominated by four species (of 17 recorded). Vegetated banks and cutbanks were the most important habitats, while riprap was among the least important for habitat use by fish. Future riprapping will probably result in a reduction in numbers for many species in the Parker II Division, but it remains unclear how flooding during data collection affected Hiebert and Grabowski's (1987) results.

Yuma Division

The major purpose of the Yuma Division study was to collect data to address potential effects of proposed channel modifications and bankline stabilization on aquatic resources, not unlike the study in the Parker II Division. The flooding events, beginning in 1983, interrupted this objective temporarily. A new objective was decided upon: to assess habitats created by the flooding with preflood conditions (Marsh and Minckley 1985). This study continued beyond the receding of floodwaters so that data could be collected postflood to address the original objective of assessing potential Yuma project impacts (Marsh and Minckley 1987).

Most of the original study areas, consisting of mainstream and backwater habitats, were affected by flooding after November 1982, with removal of vegetation, shifts in substrates, changes in river channel dimensions, and inundation of riparian vegetation (Marsh and Minckley 1985). Six habitat types were thus defined: main river channel, shallow river channel, deep backwaters (flooded floodplain), shallow backwaters (floodplain), connecting channels, and isolated pools. These habitats persisted throughout the entire study, including the period of receding floods (Marsh and Minckley

Table 39. Top three habitats identified for each species by ranking abundances from high to low in Parker II Division. X = among three habitats for each species. Adapted from Hiebert and Grabowski (1987).

	Habitat							
Species	Riprap	Cutbank	Cattail	Rootwads	Shallow	Mixed	Poston	N
Threadfin shad			X	X			X	100
Goldfish[a]				X				1
Carp		X	X	X				2,093
Red shiner		X	X	X				1,162
Yellow bullhead		X		X	X			7
Channel catfish		X	X	X				211
Flathead catfish		X		X	X			36
Mosquitofish		X	X		X			130
Striped bass		X	X	X				14
Green sunfish	X	X		X				360
Bluegill		X	X	X				2,956
Redear sunfish			X	X			X	59
Smallmouth bass	X	X	X					262
Largemouth bass		X	X	X				1,195
Black crappie			X	X	X			15
Zill's tilapia		X			X		X	81
Rainbow trout[a]		X				X		6
Total	2	13	11	13	5	1	3	
Total fishes	357	1,736	1,697	2,499	1,486	279	679	8,689

[a]Species was only found in one or two habitats.

Table 40. Ranks of abundance among technique types and habitat types for fishes in the Parker II Division. Data collected and adapted from October 1983 to August 1985 by Hiebert and Grabowski (1987). Species are ranked from high to low abundance within technique/habitats.

	Technique/all habitats				Habitats/all techniques							
Species	Hoop	Gill	Shock	Seine	Riprap	Cutbank	Cattail	Rootwad	Shallow	Mix	Poston	Total
Threadfin shad	6.5	8.0	2.0	--	--	10.0	9.0	8.0	11.0	--	4.0	7.5
Goldfish	--	17.0	--	--	--	--	--	10.5	--	--	--	17.0
Carp	1.0	2.0	1.0	8.5	2.0	2.5	1.0	2.5	3.0	1.0	2.0	2.0
Red shiner	--	4.0	--	1.0	7.5	2.5	6.5	6.0	1.0	3.5	10.5	4.0
Yellow bullhead	--	14.0	--	--	--	15.5	--	10.5	14.5	--	--	15.5
Channel catfish	6.5	7.0	3.0	7.0	6.0	7.0	4.0	6.0	8.0	8.0	7.0	6.0
Flathead catfish	5.0	11.0	5.0	--	7.5	9.0	12.0	13.5	11.0	--	10.5	11.0
Mosquitofish	--	16.0	--	2.0	--	15.5	6.5	13.5	5.0	--	--	7.5
Striped bass	--	12.5	--	--	--	13.0	10.5	16.0	14.5	--	--	12.5
Green sunfish	--	5.0	--	--	5.0	5.0	10.5	4.0	8.0	5.5	7.0	5.0
Bluegill	2.0	1.0	6.0	3.0	1.0	1.0	2.0	1.0	2.0	2.0	1.0	1.0
Redear sunfish	8.0	9.0	--	8.5	9.0	11.0	8.0	9.0	11.0	8.0	7.0	10.0
Smallmouth bass	--	6.0	--	6.0	4.0	6.0	5.0	6.0	8.0	5.5	9.0	14.0
Largemouth bass	3.0	3.0	4.0	4.0	3.0	4.0	3.0	2.5	4.0	3.5	3.0	3.0
Black crappie	--	12.5	--	--	10.0	14.0	13.5	13.5	13.0	--	--	12.5
Zill's tilapia	--	10.0	--	5.0	--	8.0	13.5	13.5	6.0	8.0	5.0	9.0
Rainbow trout	--	15.0	--	--	--	12.0	--	--	--	10.0	--	15.5
Total fishes	57	7,445	143	1,044	357	1,736	1,697	2,499	1,486	279	679	8,689

1987). Large fish were sampled with hoop, gill, and trammel nets and electrofishing, primarily in the main river channel and deep backwaters. Small fish were sampled in all habitats, except the main river channel, by seining.

Physicochemical characteristics of the Yuma Division did not differ from what would be expected, as was found in the Parker II Division study (Marsh and Minckley 1985, 1987; Hiebert and Grabowski 1987). Biomass production was also no different than expected in being low compared to other less xeric major river systems (Minckley 1979). These "stable" biotic conditions occurred during dramatic changes in river flow dynamics. Marsh and Minckley (1985) hypothesized that changes in flow were possibly not suitable for equally dramatic changes in trophic conditions; they also speculated that pesticide and herbicide residuals may have been involved, but no pertinent data existed to address this possibility.

The most important habitats for most species were deep backwaters, followed by shallow backwaters and the main channel (Table 41). The least important habitats in the Yuma Division were isolated pools and connecting channels. Backwater habitats were especially important to medium and small fish species and juvenile large fish species. The main channel was especially important to the larger fish species including striped mullet, carp, flathead catfish, and striped bass. Threadfin shad, carp, red shiner, mosquitofish, sailfin molly, and largemouth bass were especially common in backwaters the first summer and fall during flooding (Marsh and Minckley 1985). By the end of the first phase of the study, red shiner, mosquitofish, and blue tilapia were still abundant, with the other species decreasing or disappearing. Backwaters were still the most important habitats for biomass production in the system, however, and undoubtedly supported the large fish species using the main channel.

No differences were found between Phases I and II in the ranking of fish abundances among sampling techniques (Table 42). However, there were differences between the phases in the relative ranking of species in some habitats (Table 43). These changes were statistically notable in the main channel, connecting channel, and isolated pools. The former habitat was subject to a dramatic increase in the ranking of threadfin shad from being absent in Phase I to being the second most common fish in Phase II. Concomitant with this, blue tilapia declined from being the second most common fish to being eighth in the main channel. Connecting channels and isolated pools experienced dramatic declines in species richness and equally dramatic changes in relative ranks of species abundances; these changes were primarily due to drying and nutrient depletion through time. Overall though, there was a strong association between the two phases of study and the relative rankings of total abundances among fish species. Noticeable changes in absolute numbers between the two phases were declines in sailfin molly, black crapple, and blue tilapia, while increases were noted in goldfish and threadfin shad; these changes were not all necessarily borne out in the ranking procedure.

The most abundant fish species overall were red shiner, mosquitofish, blue tilapia, and threadfin shad. Large fishes were dominated by carp, threadfin shad, blue tilapia, and largemouth bass. Striped mullet, flathead catfish, and blue tilapia were the most frequently sampled by

Table 41. Top three habitats identified for each species in Yuma Division as identified by Marsh and Minckley (1987). Some species were restricted to less than three habitats, and other species are deleted because primary habitats could not be determined. X = among top three habitats.

	Habitat						
Species[a]	Main channel	Shallow channel	Deep backwater	Shallow backwater	Connecting channel	Isolated pool	N
Striped mullet	X	X	X				518
Threadfin shad		X	X	X			6,896
Goldfish	X		X	X			2,044
Carp	X		X	X			7,861
Red shiner		X		X	X		43,555
Channel catfish	X		X	X			375
Flathead catfish	X	X	X				880
Mosquito-fish		X	X	X			9,633
Sailfin molly		X	X	X			5,169
Striped bass	X		X				90
Warmouth			X				111
Bluegill	X		X	X			1,048
Redear sunfish	X		X	X			707
Largemouth bass	X	X	X				1,699
Black crappie	X		X				139
Blue tilapia		X	X	X			12,486
Zill's tilapia				X			4
Total species	10	8	15	11	1	0	

[a]Other species sampled were yellow bullhead (N = 4), green sunfish (N = 5), Mexican molly (N = 1), and smallmouth bass (N = 1).

Table 42. Ranks of abundance among technique types comparing Phase I (1982-1984) and Phase II (1985-1886) of Yuma Division study (Marsh and Minckley 1985, 1987). Abundances are ranked from high to low densities for each technique type. Ranks in parentheses are for species with zero abundance during one phase.

	Technique/Phase									
	Hoop		Gill/trammel		Electroshock		Seine		Total	
Species	I	II	I	II	I	II	I	II	I	II
Striped mullet	5.0	10.5	5.0	9.5	3.0	2.0	--	--	11.0	12.0
Threadfin shad	6.0	2.0	1.0	1.0	6.0	3.0	6.0	4.0	5.0	4.0
Goldfish	11.0	(13.0)	9.0	6.0	7.0	7.0	10.5	3.0	13.0	3.0
Carp	1.0	3.0	2.0	4.0	1.0	4.0	4.0	10.0	4.0	10.0
Red shiner	--	--	--	--	--	--	1.0	1.0	1.0	1.0
Yellow bullhead	--	--	--	--	--	--	13.0	15.0	16.0	19.0
Channel catfish	4.0	6.0	6.0	5.0	8.0	10.0	10.5	13.0	10.0	14.0
Flathead catfish	7.0	4.0	8.0	(13.0)	5.0	1.0	14.0	(17.0)	12.0	7.5
Mosquitofish	--	--	--	--	--	--	3.0	2.0	3.0	2.0
Sailfin molly	--	--	--	--	--	--	5.0	7.0	6.0	7.5
Mexican molly	--	--	--	--	--	--	(16.5)	15.0	(20.0)	19.0
Striped bass	12.0	(13.0)	11.0	(13.0)	9.0	8.0	--	--	15.0	15.0
Green sunfish	13.5	(13.0)	(14.0)	9.5	12.0	(15.0)	--	--	18.0	19.0
Warmouth	13.5	10.5	13.0	(13.0)	(14.0)	13.0	15.0	15.0	17.0	16.5
Bluegill	3.0	1.0	10.0	7.0	10.0	9.0	9.0	8.0	8.0	9.0
Redear sunfish	9.0	6.0	7.0	9.5	11.0	13.0	8.0	9.0	9.0	11.0
Smallmouth bass	--	--	--	--	(14.0)	13.0	--	--	(20.0)	19.0
Largemouth bass	10.0	8.0	4.0	2.0	4.0	5.0	7.0	6.0	7.0	6.0
Black crappie	8.0	6.0	12.0	9.5	(14.0)	11.0	12.0	11.0	14.0	13.0
Blue tilapia	2.0	9.0	3.0	3.0	2.0	6.0	2.0	5.0	2.0	5.0
Zill's tilapia	--	--	--	--	--	--	(16.5)	12.0	(20.0)	16.5

(Continued)

Table 42. (Concluded)

Species	Hoop I	Hoop II	Gill/trammel I	Gill/trammel II	Electroshock I	Electroshock II	Seine I	Seine II	Total I	Total II
Number of species	14	11	13	11	12	14	15	16	18	21
N	14		14		15		17		21	
r_s	0.705		0.723		0.824		0.823		0.854	
P	<0.005		<0.005		<0.001		<0.001		<0.001	
Total fish	1,592	257	1,347	194	2,183	1,100	58,365	28,577	63,487	29,577

Table 43. Ranks of abundance among habitats comparing Phase I (1982-1984) and Phase II (1985-1986) of Yuma Division study (Marsh and Minckley 1985, 1987). Abundances are ranked from high to low densities for each habitat type. Ranks in parentheses are for species with zero abundance during one phase.

					Deep backwater									
	Main channel		Shallow channel		Large fish		Small fish		Shallow backwater		Connecting channel		Isolated pools	
Species	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Striped mullet	4	3	--	--	3	2	--	--	--	--	--	--	--	--
Threadfin shad	(14.5)	2	5	4	(14)	1	4	8	9	3	7	(11.5)	1	(12.5)
Goldfish	5	12	11.5	2	9	5	9	1	12.5	4	12	2	10	1
Carp	1	4	6	(12)	1	4	1	9	8	10	5	5.5	3	5
Red shiner	--	--	1	1	--	--	2	3	1	1	1	1	2	2
Yellow bullhead	--	--	14	(12)	--	--	14	(14)	14.5	11.5	12	(11.5)	11.5	(12.5)
Channel catfish	9	8	9	(12)	5	7	11	(14)	10.5	14.5	8	(11.5)	9	(12.5)
Flathead catfish	3	1	14	(12)	8	6	14	(14)	14.5	(17)	12	(11.5)	11.5	(12.5)
Mosquitofish	--	--	4	6	--	--	5	2	3	2	2	(11.5)	5	(12.5)
Sailfin molly	--	--	2	7.5	--	--	7	5	4	6	3	(11.5)	14.5	(12.5)
Mexican molly	--	--	--	--	--	--	--	--	(16.5)	14.5	--	--	--	--
Striped bass	10	8	--	--	11	(13.5)	--	--	--	--	--	--	--	--
Green sunfish	12	(15)	--	--	12	10.5	--	--	--	--	--	--	--	--
Warmouth	13	13	14	(12)	13	10.5	14	12	12.5	(19)	12	(11.5)	14.5	6
Bluegill	8	5	8	7.5	6	8	8	6.5	6	8	12	5.5	8	4
Redear sunfish	7	10	10	(12)	7	(13.5)	10	11	5	9	12	7	6	(12.5)
Smallmouth bass	(14.5)	14	--	--	--	--	--	--	--	--	--	--	--	--
Largemouth bass	6	6	7	3	4	3	6	4	7	7	6	3	7	3
Black crappie	11	11	11.5	(12)	10	9	12	10	10.5	13	12	(11.5)	13	(12.5)
Blue tilapia	2	8	3	5	2	3	3	6.5	2	5	4	4	4	7
Zill's tilapia	--	--	--	--	--	--	--	--	(16.5)	11.5	--	--	16	8

(Continued)

Table 43. (Concluded)

					Deep backwater									
	Main channel		Shallow channel		Large fish		Small fish		Shallow backwater		Connecting channel		Isolated pools	
Species	I	II	I	II	I	II	I	II	I	II	I	II	I	II
Number of species	13	14	15	8	13	11	15	12	15	15	15	7	16	8
N	15		15		14		15		17		15		16	
r_s	0.281		0.552		0.466		0.565		0.711		0.140		0.188	
P	NS		<0.025		<0.05		<0.025		<0.001		NS		NS	

electroshocking; this technique typically allows study of species that are otherwise difficult to sample.

Comparison Among Studies

Similarities between Parker II and Yuma were found for species composition and rank of abundance in hoop net and electroshocking samples (Table 44). These two techniques sampled deeper waters. Gill/trammel nets and seine samples were not statistically similar between the two divisions, indicating different species compositions and rank of abundances in shallower habitats. Striped mullet, sailfin molly, and blue tilapia were absent from Parker II, while they were numerically important species in the Yuma Division. Conversely, green sunfish, bluegill, and smallmouth bass were more numerous and ranked significantly higher in the Parker II Division than they did in the Yuma Division. Colder water in the Parker II Division influenced smallmouth bass numbers positively, while sailfin molly and blue tilapia were negatively affected. Striped mullet are only known from the lowermost reaches of the lower Colorado River where young spread periodically (with high flows) north of Morelos Dam. Carp, red shiner, and mosquitofish were ranked high in both divisions.

Comparisons between Minckley's (1979) study and Marsh and Minckley's (1985, 1987) studies are restricted to seining samples in shallow main channel and backwater habitats and net sampling in the main channel. Flathead catfish, striped bass, black crappie, blue tilapia, and striped mullet went unrecorded in the mid-1970's, while mouthbrooder went unrecorded in the mid-1980's (Table 45). Rank order of abundance was statistically similar in backwater habitats even though only 4 species were recorded in the mid-1970's, while 17 species were found in the mid-1980's. Relative ranks of threadfin shad, carp, red shiner, channel catfish, mosquitofish, sailfin molly, bluegill, and largemouth bass remained largely unchanged through the decade.

There were dramatic changes in species composition and relative abundances between the two studies, but these were not all easily interpretable with respect to flooding (Marsh and Minckley 1987). Decreases in mouthbrooder and increases in red shiner and blue tilapia occurred before flooding. The large-fish community in the main channel changed dramatically after flooding, with the 1983 (preflood) community being similar to the mid-1970's community (Marsh and Minckley 1987). Some species were apparently transported from upstream (i.e., threadfin shad, striped bass, and many centrarchids), while other species expanded from the south (notably the native striped mullet). In addition, flathead catfish has expanded notably in the main channel since flooding in response to increased habitat in the channel and, possibly, from an increased forage base.

Backwaters in the mid-1980's were characterized by high species richness among large fish, probably related to movements from the main channel into these newly created habitats. Backwaters created during and after the 1983 flooding were dissimilar to the old backwaters studied in the mid-1970's (Marsh and Minckley 1985, 1987). The older backwaters, small in areal extent, were connected with the main channel, moderated temperature and physical characteristics, and provided extensive submergent beds of vegetation. These older backwaters, in turn, supported high invertebrate biomass. The new backwaters formed over barren agricultural fields and open stands of riparian vegetation

Table 44. Comparison betwen Yuma (Phases I and II combined) and Parker II Divisions by technique during and after flooding. Ranks in parentheses are for species absent.

	Hoop		Gill/Trammel		Electroshock		Seine		Total	
Species	Parker II	Yuma	Parker II	Yuma	Parker II	Yuma	Parker II	Yuma	Parker II	Yuma
Striped mullet	(11.0)	7.0	(18.5)	5.0	(11.0)	4.0	--	--	(20.0)	12.0
Threadfin shad	6.5	4.0	8.0	1.0	2.0	5.0	(13.5)	5.0	7.5	5.0
Goldfish	(11.0)	11.0	17.0	8.0	(11.0)	7.0	(13.5)	7.0	17.0	7.0
Carp	1.0	1.0	2.0	2.0	1.0	2.0	8.5	4.0	2.0	4.0
Red shiner	--	--	4.0	(17.0)	--	--	1.0	1.0	4.0	1.0
Yellow bullhead	--	--	14.0	(17.0)	--	--	(13.5)	13.0	15.5	17.0
Channel catfish	6.5	5.0	7.0	6.0	3.0	8.0	7.0	11.0	6.0	13.0
Flathead catfish	5.0	6.0	11.0	9.5	5.0	1.0	(13.5)	14.0	11.0	10.0
Mosquitofish	--	--	16.0	(17.0)	--	--	2.0	3.0	7.5	3.0
Sailfin molly	--	--	--	--	--	--	(13.5)	6.0	(20.0)	6.0
Mexican molly	--	--	--	--	--	--	(13.5)	17.0	(20.0)	6.0
Striped bass	(11.0)	13.0	12.5	11.0	(11.0)	9.0	--	--	12.5	15.0
Green sunfish	(11.0)	14.0	5.0	13.5	(11.0)	14.0	--	--	5.0	19.0
Warmouth	(11.0)	12.0	(18.5)	13.5	(11.0)	14.0	(13.5)	15.5	(20.0)	16.0
Bluegill	2.0	2.0	1.0	9.5	6.0	10.0	3.0	9.0	1.0	9.0
Redear sunfish	8.0	9.0	9.0	7.0	(11.0)	11.0	8.5	10.0	10.0	11.0
Smallmouth bass	--	--	6.0	(17.0)	(11.0)	14.0	6.0	18.0	14.0	20.5
Largemouth bass	3.0	10.0	3.0	4.0	4.0	6.0	4.0	8.0	3.0	8.0
Black crappie	(11.0)	8.0	12.5	12.0	(11.0)	12.0	(13.5)	12.0	12.5	14.0
Blue tilapia	(11.0)	3.0	10.0	3.0	(11.0)	3.0	(13.5)	2.0	(20.0)	2.0
Zill's tilapia	--	--	--	--	--	--	5.0	15.5	9.0	18.0
Rainbow trout	--	--	15.0	(17.0)	--	--	--	--	15.5	(22.0)
Number of species	7	14	17	14	6	15	9	17	17	21
N	14		19		15		18		22	
r_s	0.586		0.108		0.503		0.293		0.503	
P	<0.025		NS		<0.05		NS		NS	

Table 45. Comparisons of Minckley's (1979) study with more recent studies in the Yuma (Marsh and Minckley 1985, 1987) and Parker II (Hiebert and Grabowski 1987) Divisions. Ranks in parentheses are for species absent.

	Yuma Division						Parker II Division					
	Main channel seining		Main channel net		Backwater seining		Main channel seining		Poston Wasteway net		Overall	
Species	1974-1975	1983-1986	1974-1975	1983-1986	1974-1975	1983-1986	1974	1983-1985	1974	1983-1985	1974	1983-1985
Threadfin shad	1.0	5.0	(10.5)	7.0	(10.5)	5.0	2.0	(12.0)	(10.0)	4.0	8.0	7.5
Goldfish	(14.5)	12.0	(10.5)	12.0	3.0	10.0	--	--	--	--	(14.0)	17.0
Carp	(14.5)	4.0	1.0	1.0	(10.5)	9.0	4.0	8.5	1.0	2.0	4.0	2.0
Red shiner	3.0	1.0	--	--	1.0	1.0	1.0	1.0	(10.0)	10.5	6.0	4.0
Yellow bullhead	10.0	14.0	5.5	(13.5)	(10.5)	13.0	11.0	(12.0)	5.5	(12.0)	8.0	15.5
Channel catfish	(14.5)	9.0	3.5	5.5	4.0	12.0	9.0	7.0	2.0	7.0	2.0	6.0
Flathead catfish	(14.5)	14.0	(10.5)	3.0	(10.5)	16.5	--	--	(10.0)	10.5	(14.0)	11.0
Mosquitofish	5.0	2.0	--	--	2.0	2.0	3.0	2.0	--	--	9.0	7.5
Sailfin molly	2.0	3.0	--	--	(10.5)	4.0	--	--	--	--	--	--
Mexican molly	9.0	(17.0)	--	--	(10.5)	16.5	--	--	--	--	--	--
Striped bass	--	--	(10.5)	16.5	--	--	--	--	--	--	(14.0)	12.5
Green sunfish	8.0	(17.0)	--	--	--	--	8.0	(12.0)	7.0	7.0	7.0	5.0
Warmouth	(14.5)	14.0	--	--	(10.5)	15.0	12.5	(12.0)	--	--	--	--
Bluegill	6.0	8.0	2.0	2.0	(10.5)	6.0	5.0	3.0	5.5	1.0	3.0	1.0
Redear sunfish	(14.5)	10.0	5.5	10.0	(10.5)	8.0	7.0	8.5	4.0	7.0	1.0	10.0
Smallmouth bass	--	--	--	--	--	--	12.5	6.0	(10.0)	9.0	(14.0)	14.0
Largemouth bass	7.0	7.0	(10.5)	4.0	(10.5)	7.0	6.0	4.0	3.0	3.0	5.0	3.0
Black crappie	(14.5)	11.0	(10.5)	8.5	(10.5)	11.0	10.0	(12.0)	--	--	(14.0)	12.5
Blue tilapia	(14.5)	6.0	(10.5)	11.0	(10.5)	3.0	--	--	--	--	--	--
Zill's tilapia	--	--	--	--	(10.5)	14.0	(13.0)	5.0	(10.0)	5.0	(14.0)	9.0

(Continued)

Table 45. (Concluded)

Species	Yuma Division: Main channel seining 1974-1975	Yuma Division: Main channel seining 1983-1986	Yuma Division: Main channel net 1974-1975	Yuma Division: Main channel net 1983-1986	Yuma Division: Backwater seining 1974-1975	Yuma Division: Backwater seining 1983-1986	Parker II Division: Main channel seining 1974	Parker II Division: Main channel seining 1983-1985	Parker II Division: Poston Wasteway net 1974	Parker II Division: Poston Wasteway net 1983-1985	Parker II Division: Overall 1974	Parker II Division: Overall 1983-1985
Mouthbrooder	4.0	(17.0)	3.5	(13.5)	--	--	--	--	--	--	--	--
Rainbow trout	--	--	--	--	--	--	--	--	--	--	(14.0)	15.5
Number of species	10	15	6	12	4	17	13	9	7	11	10	17
N	18		14		17		14		12		17	
r_s	0.348		0.220		0.561		0.434		0.424		0.758	
P	NS		NS		<0.025		NS		NS		<0.001	

were not necessarily nutrient poor, but may have contained residual pesticides and herbicides; in the summers of 1983 and 1984 several thousand hectares were sprayed with malathion, targeting mosquito larvae, which also probably affected many aquatic invertebrate taxa (Levy et al. 1987; Marsh and Minckley 1987). Increased surface area moderated to some extent the biomass-poor conditions of the new backwaters. The new habitats harbored high numbers of smaller fish species and individuals early during flooding, but numbers of small fish diminished significantly by the end of 1986. The lack of nutrients, submergent vegetation, and invertebrates was probably responsible for these declines. Overall though, both old and new backwaters were important as spawning, nursery, and foraging areas and hiding places for the medium- and small-sized species.

Marsh and Minckley (1987) concluded that backwaters continue to be critical for maintaining healthy and large populations of many fish species in the Yuma Division. Current plans to deepen the channel through the Yuma Division and armor the levees with riprap would severely lessen the extent of backwaters and their connections with the channel. These activities would also decrease habitats within the main channel by removing heterogeneity on the bottom and margins. The loss of backwaters will affect successful recruitment of centrarchids, especially largemouth bass, and modifying the main channel will reduce numbers of larger fishes, especially flathead catfish and striped bass, all of which are important sport fishes.

Comparisons in the Parker II Division between the mid-1970's and mid-1980's reveal some different trends than found in the Yuma Division. As with the Yuma Division, more species overall were found during the more intensive efforts of the mid-1980's study in the Parker II Division (Table 45). In main channel seining samples there were few dramatic changes except for a complete disappearance of juvenile threadfin shad, which were the second highest ranked species in the mid-1970's. Other noticeable, but less dramatic, changes in rank were declines in juvenile carp and green sunfish, with increases in juvenile smallmouth bass and Zill's tilapia.

The Poston Wasteway is the largest intake into the main channel in the Parker II Division and has characteristics, both biotic and abiotic, similar to backwaters. Hoop and gill/trammel net samples, as with main channel seining, indicated few dramatic changes. Here, large threadfin shad, bluegill, and Zill's tilapia increased, while yellow bullhead, channel catfish, and redear sunfish decreased in ranking through time.

There were few changes overall in ranking abundance among species, with declines found in yellow bullhead, channel catfish, and redear sunfish, and with only one species ranked dramatically higher, Zill's tilapia. Species found in the later study, but absent during the earlier study, were goldfish, flathead catfish, striped bass, black crappie, Zill's tilapia, and rainbow trout. As in the Yuma Division, some species were probably present from being forced downstream by high water, including striped bass and rainbow trout. Unlike the Yuma Division, Parker II Division experienced few changes among many of the small fish species. No clear effects from flooding were detected, but the later study may have been terminated too early to determine long-term flood-related changes.

Channel modification and regulation of flows have influenced the decline and eventual extirpation of all but one native species. These changes also assisted in the establishment of an introduced ichthyofauna, much of which is composed of sport fishes. Ironically, continued channel deepening, armoring of levees, and depletion of backwaters will negatively affect most, if not all, major sport fish species (see Beland 1953). Isolation of backwaters and loss of heavily vegetated banks will reduce reproduction and growth potential for nearly all medium-sized fish. Loss of those species will, in turn, reduce food sources for large piscivorous species, which are almost all sport fish species. The future maintenance of a healthy sport fishery throughout the lower Colorado River system may be hampered by water management activities, especially with continued proposals to modify the river as in the Parker II and Yuma Divisions.

9.7 LISTED SPECIES AND SPECIES OF SPECIAL CONCERN

Presently, five species, woundfin, bonytail chub, desert pupfish, Gila topminnow, and Colorado squawfish, are on the Federal endangered species list. These species no longer occur in the system, except for a few bonytail chub in Lake Mohave. In addition, roundtail (Colorado River) chub and razorback sucker are listed as species of special concern to Nevada, California, and Arizona. The razorback sucker, the only native freshwater fish with a large extant population, receives the most attention on the Colorado River at present.

The legal and management status of the razorback sucker has created much debate between managers of the upper and lower basins. Several populations persist in the upper basin, primarily along the Green and upper Colorado Rivers; however, this unlisted species is much rarer than some other listed species (excepting bonytail chub). Managers in the upper basin support Federal listing of the razorback sucker as threatened in order to maintain extant populations (Brooks 1987; McAda 1987; Tyus 1987b).

The razorback sucker in the lower basin appears to be reduced to one large extant population, with no evidence of extensive successful recruitment (Minckley 1983). In contrast to the upper basin, lower basin managers deferred listing until 1991, based on Memorandums of Understanding between California Department of Fish and Game, Arizona Department of Game and Fish, and the U.S. Fish and Wildlife Service. This deferment was in an attempt to conduct widespread reintroduction and monitoring efforts combined with research to determine reasons for decline, life-history characteristics, and prospects for recovery (Brooks 1987; Marsh 1987; Ulmer 1987). The rationale for this strategy is that Federal listing of the razorback sucker in the lower basin would severely restrict reintroduction efforts because of necessitated interagency consulation involved with reestablishing threatened or endangered populations. Some Federal and State agencies are reluctant to reestablish populations under their jurisdiction which are protected under Section 7 of the Endangered Species Act of 1973 (Johnson and Rinne 1982).

Reintroductions of razorback suckers into the lower Colorado River and elsewhere in Arizona have occurred periodically during the 1970's and 1980's (Minckley 1983; Johnson 1985; Ulmer 1987; Gronowski 1987b). The collection of several subadult razorback suckers (≤360 mm [≤14 inches] in total length) in Lake Mohave, Coachella Canal, and near Parker may suggest some survival of wild progeny on the lower Colorado River, but more likely represent escapees and survivors from previous attempts (Minckley 1983; Ulmer 1987; Langhorst 1987b). A concerted effort to introduce and monitor razorback suckers, undertaken by the California Department of Fish and Game with the cooperation of the U.S. Fish and Wildlife Service, began in 1987 and is to continue for about 10 years (Langhorst 1987b; Ulmer 1987).

Release of razorback suckers (with average total length 200 mm [8 inches]) on the lower Colorado River in 1987 resulted in very few recaptures within several days after release (Langhorst 1987b). These results are similar to those found with releases elsewhere in Arizona (Marsh 1987). Recommendations are being made to hold young razorback sucker in stock pens until they are of a size to reduce depredation from most centrarchids. Additional recommendations include conducting releases during winter with relatively few individuals over a longer time span, when predator activity is lower and so swarms of predators may be better avoided (Marsh 1987). Federal listing will likely proceed in the lower basin if reintroduction efforts prove unsuccessful in establishing self-reproducing populations. Since natural recruitment is essentially nonexistent presently, the future status of razorback suckers on the lower Colorado River may be completely dependent on the reintroduction of adults into the system.

Recovery plans for many Federal listed fish species, formerly occurring on the lower Colorado River, invariably include reintroduction efforts (Johnson 1980, 1985, 1987). The resistance to reintroduction efforts by some agencies was countered by the development of a new listing category, proposed by the Desert Fishes Council, which was amended to the Endangered Species Act in 1982 and published in the Federal Register, 27 August 1984 (Johnson 1987). Thus, experimental listings were added to threatened and endangered statuses. Two subcategories were defined: (1) essential, with critical habitat designation possible and (2) nonessential, without critical habitat designation. Experimental listing allows for reintroductions without the very strict protective regulations found in threatened and endangered statuses. Essential experimental populations are afforded threatened protection, whereas nonessential experimental populations are afforded proposed species protection. Experimental populations are to be reintroduced within the probable historic range of the species in question, but geographically isolated from fully protected populations of the same species. Finally, the public must be allowed to comment before introductions can be conducted (Johnson 1987). The experimental designation strikes a compromise in allowing widespread reintroductions of listed species in areas where it would be otherwise a political impossibility.

Experimental populations, especially nonessential, may become more widely used for reintroducing native fishes throughout the Southwest. Under the guise of a nonessential population, the Colorado squawfish may be introduced between Parker and Imperial Dams to establish a sport fishery, as published in the Federal Register, 26 August 1987. This middle reach meets the requirements for an experimental population by being within the historical range, while being isolated from all other Colorado squawfish populations.

Other listed native fish species may also be reintroduced on or near the lower Colorado River. Under experimental status, native fish may be maintained in semi-artificial backwaters or ponds which are kept free of introduced fishes. Bonytail chub, woundfin, Gila topminnow, and desert pupfish could be candidates for such programs. However, maintaining stable populations for several or all of these species may require perpetual reintroductions, not unlike that being experienced in razorback sucker recovery efforts.

Although artificial reestablishment may be possible, the future of the native ichthyofauna on the lower Colorado River remains bleak. Improvement in the ecological health of most native species will not change unless dramatic changes in the management of water flows and control of introduced species are undertaken. Endemic Southwestern fish species compose an evolutionary unique group with specific and often bizarre adaptations for arid and highly variable aquatic environments (Minckley et al. 1986). Perhaps the most compelling reason for preserving these relict species was summarized by Minckley and Deacon (1968:1431):

> ...A great natural experiment of evolution, also amplified and perhaps accelerated by isolation in desert aquatic habitats, appears about to become an exercise in extinction, if man will have it so.

CHAPTER 10. HERPETOFAUNAL COMMUNITIES

Information on reptiles and amphibians occurring on the lower Colorado River is limited. Earliest faunal surveys paid relatively little attention to these animals (Cooper 1869; Coues 1875; Grinnell and Camp 1917). Most of our present knowledge of lower Colorado River reptiles and amphibians is summarized in a series of papers by Vitt and Ohmart (1974, 1975, 1977a,b, 1978) and by reports by Anderson and Ohmart (1982a,b). The following discussions are supported by these papers unless otherwise noted.

Fifty-five species of reptiles and amphibians have been documented from the lower Colorado River. Among these are 1 salamander, 6 toads, 3 tree-frogs, 3 true frogs, 4 turtles, 1 crocodilian, 18 lizards, and 19 snakes (Table 46). The tiger salamander (Ambystoma tigrinum), mountain tree-frog (Hyla wrightorum), bullfrog, Rio Grande leopard frog (Rana berlandieri), spiny softshell, and American alligator (Alligator mississippiensis) are known introductions by man. An additional seven species (one lizard and six snakes) are suspected of occurring along the lower Colorado River, but are not documented (Table 47) (Vitt and Ohmart 1978).

10.1 HABITAT USE

Lower Colorado River reptiles and amphibians can be found in all terrestrial and aquatic habitats, including those which are influenced by the presence of humans. Habitats can be generally categorized into rocky substrate, sandy substrate, riparian, aquatic, upland desert, and agricultural-residential. There is some overlap among these categories as aquatic habitats occur in agricultural areas (canals, ditches) and sandy areas occur in riparian areas (some honey mesquite stands). Among species, there are those which are ubiquitous as well as others which are local in habitat use. Finally, some species are local in distribution even though their habitat may be more extensive. The lower Colorado River marks a zone of interchange between the Sonoran and Mohave Deserts, although for some species there is no dispersal between the biogeographical regions.

Rocky substrate is occupied by four species of reptiles (Table 46). These are the chuckwalla (Sauromalus obesus), desert collared lizard (Crotaphytus insularis), Sonoran lyre snake (Trimorphodon lambda), and speckled rattlesnake (Crotalus mitchelli). Chuckwallas are most common in large piles of boulders, along cliffs (as at Parker Dam), and in rocky mountainous areas; they are also most common where firearms are prohibited as they are popular targets for shooting practice (Vitt and Ohmart 1978). The desert collared lizard, Sonoran lyre snake, and speckled rattlesnake are also found among boulder piles, but they are most frequently found at the base of small mountains and in gravelly areas at the periphery of large washes.

Table 46. Habitats, distribution, abundance, and status of reptiles and amphibians on the lower Colorado River. Habitat: A = aquatic, R = riparian, Ag-R = agricultural-residential, D = upland desert; Substrate: S = sandy, R = rocky; Distribution: N-S division = Parker Dam and the Bill Williams confluence, E-W division = the main channel of the Colorado River (Figure 1); Abundance: C = common, U = uncommon, R = rare, E = extirpated; Sta. (Status): N = native, I = introduced.

	Habitat				Sub-strate		Distribution				Abundance				Sta.	
Species	A	R	Ag-R	D	S	R	NE	NW	SE	SW	C	U	R	E	N	I
Tiger salamander (<u>Ambystoma tigrinum</u>)	X				X		X	X	X	X		X				X
Couch's spadefoot toad (<u>Scaphiopus couchii</u>)	X	X	X	X	X		X	X	X	X		X			X	
Sonoran Desert toad (<u>Bufo alvarius</u>)	X	X	X	X	X				X	X	X				X	
Great Plains toad (<u>Bufo cognatus</u>)	X	X	X		X		X	X	X	X	X				X	
Red-spotted toad (<u>Bufo punctatus</u>)	X	X		X	X		X	X	X	X	X				X	
Woodhouse's toad (<u>Bufo woodhousei</u>)	X	X	X		X		X	X	X	X	X				X	
Southwestern toad (<u>Bufo microscaphus</u>)	X	X			X		X	X					X		X	
Canyon treefrog (<u>Hyla arenicolor</u>)	X	X				X	X						X		X	
Pacific treefrog (<u>Hyla regilla</u>)	X	X						X					X		X	
Mountain treefrog (<u>Hyla eximia</u>)	X	X						X						X		X
Bullfrog (<u>Rana catesbeiana</u>)	X	X	X		X		X	X	X	X	X					X
Lowland leopard frog (<u>Rana yavapaiensis</u>)	X	X			X		X	X	X	X				X?	X	
Rio Grande leopard frog (<u>Rana berlandieri</u>)	X	X			X				X	X	X					X
Yellow mud turtle (<u>Kinosternon flavescens</u>)	----------records retracted----------															
Sonoran mud turtle (<u>Kinosternon sonoriense</u>)	X	X			X				X	X			X		X?	

(Continued)

Table 46. (Continued)

Species	Habitat				Sub-strate		Distribution				Abundance				Sta.	
	A	R	Ag-R	D	S	R	NE	NW	SE	SW	C	U	R	E	N	I
Spiny softshell turtle (*Trionyx spiniferus*)	X	X	X		X		X	X	X	X	X					X
Desert tortoise (*Gopherus agassizii*)			X	X	X	X	X	X	X	X		X			X	
American alligator (*Alligator mississippiensis*)	X	X			X									X		X
Leaf-toed gecko (*Phyllodactylus xanti*)				X			X			X			X		X	
Western banded gecko (*Coleonyx variegatus*)		X	X	X	X	X	X	X	X	X	X				X	
Desert iguana (*Dipsosaurus dorsalis*)		X	X	X	X		X	X	X	X	X				X	
Chuckawalla (*Sauromalus obesus*)				X		X	X	X	X	X	X				X	
Zebra-tailed lizard (*Callisaurus draconoides*)		X	X	X	X		X	X	X	X	X				X	
Colorado Desert fringe-toed lizard (*Uma notata*)				X	X				X	X	X[a]				X	
Mohave fringe-toed lizard (*Uma scoparia*)		X		X	X			X	X	X	X[a]				X	
Desert collared lizard (*Crotaphytus insularis*)				X		X	X	X	X	X		X			X	
Long-nosed leopard lizard (*Gambelia wislizenii*)				X	X		X	X	X	X		X			X	
Desert spiny lizard (*Sceloporus magister*)		X	X	X	X	X	X	X	X	X	X				X	

(Continued)

Table 46. (Continued)

Species	Habitat				Sub-strate		Distribution				Abundance				Sta.	
	A	R	Ag-R	D	S	R	NE	NW	SE	SW	C	U	R	E	N	I
Side-blotched lizard (*Uta stansburiana*)		X	X	X	X	X	X	X	X	X	X				X	
Long-tailed brush lizard (*Urosaurus graciosus*)				X			X	X	X	X	X				X	
Tree lizard (*Urosaurus ornatus*)		X					X	X	X	X	X				X	
Desert horned lizard (*Phyrnosoma platyrhinos*)				X	X		X	X	X	X		X			X	
Flat-tailed horned lizard (*Phyrnosoma mcalli*)				X	X				X	X		X[a]			X	
Desert night lizard (*Xantusia vigilis*)				X			X	X					X		X	
Western whiptail (*Cnemidophorus tigris*)		X	X	X	X	X	X	X	X	X	X				X	
Gila monster (*Heloderma suspectum*)			X	X	X	X	X	X					X		X	
Western blind snake (*Leptotyphlops humilis*)		X	X	X	X		X	X	X	X	X				X	
Spotted leaf-nosed snake (*Phyllorhynchus decurtatus*)		X		X	X		X	X	X	X	X				X	
Coachwhip snake (*Masticophis flagellum*)		X	X	X	X	X	X	X	X	X	X				X	
Western patch-nosed snake (*Salvadora hexalepis*)		X	X	X	X	X	X	X	X	X	X				X	
Glossy snake (*Arizona elegans*)			X	X	X		X	X	X	X	X				X	
Gopher snake (*Pituophis melanoleucus*)		X	X	X	X	X	X	X	X	X	X				X	
Common kingsnake (*Lampropeltis getulus*)		X	X	X	X	X	X	X	X	X	X				X	

(Continued)

Table 46. (Concluded)

Species	Habitat				Sub-strate		Distribution				Abundance				Sta.	
	A	R	Ag-R	D	S	R	NE	NW	SE	SW	C	U	R	E	N	I
Long-nosed snake (*Rhinocheilus lecontei*)		X	X	X	X		X	X	X	X	X				X	
Checkered garter snake (*Thamnophis marcianus*)	X	X			X				X	X			X		X	
Mexican garter snake (*Thamnophis eques*)	X	X			X		X		X					X?	X	
Groundsnake (*Sonora episcopa*)		X	X	X	X		X	X	X	X		X			X	
Western shovel-nosed snake (*Chionactis occipitalis*)				X	X		X	X	X	X	X				X	
Banded sand snake (*Chilomeniscus cinctus*)				X	X				X				X		X	
Lyre snake (*Trimorphodon biscutatus*)				X		X	X	X	X	X		X			X	
Night snake (*Hypsiglena torquata*)			X	X	X	X	X	X	X	X		X			X	
Western diamondback rattlesnake (*Crotalus atrox*)		X	X	X	X	X	X	X	X	X	X				X	
Speckled rattlesnake (*Crotalus mitchelli*)				X		X	X	X	X	X	X[a]				X	
Sidewinder (*Crotalus cerastes*)		X	X	X	X		X	X	X	X	X[a]				X	
Mohave rattlesnake (*Crotalus scutulatus*)		X	X	X	X	X	X	X	X			X			X	

[a]In appropriate habitat.

Table 47. Additional species which may occur on the lower Colorado River.

Species	Chances of occurring
Many-lined skink (Eumeces multivirgatus)	Unlikely
Rosy boa (Lichanura trivigata)	Unlikely
Ringneck snake (Diadophis punctatus)	Unlikely
Striped whipsnake (Masticophis taeniatus)	Likely
Sonoran mountain kingsnake (Lampropeltis pyromelara)	Unlikely
Arizona coral snake (Micturoides euryxanthus)	Unlikely
Black-tailed rattlesnake (Crotalus molossus)	Likely

Sandy substrate serves as habitat for seven lizard and seven snake species. The most frequently encountered species are desert iguana (Dipsosauraus dorsalis), zebra-tailed lizard (Callisaurus draconoides), glossy snake (Arizona elegans), and longnosed snake (Rhinocheilus lecontei). The two latter species are chiefly nocturnal and are often encountered in sandy agricultural areas. Three lizard species, the Mohave and Colorado Desert fringe-toed lizards (Uma scoparia and U. notata, respectively) and flat-tailed horned lizard (Phrynosoma mcallii) are relatively restricted to the lower Colorado River Valley and adjacent deserts. The Mohave fringe-toed lizard can be found locally in honey mesquite stands on sandy soil. Otherwise, sand substrate species are largely absent from riparian areas.

Nine species of reptiles and amphibians are considered strictly riparian with all but one of them being semiaquatic. Many of these species are presently local or have been extirpated from the river, including southwestern toad (Bufo microscaphus), Pacific treefrog (Hyla regilla), lowland leopard frog (Rana yavapaiensis), Mexican garter snake (Thamnophis eques), and checkered garter snake (T. marcianus). Only the introduced bullfrog and the native red-spotted toad (Bufo punctatus) are common riparian species. The only strictly terrestrial riparian species is the ornate tree lizard (Urosaurus ornatus), which is mostly arboreal in large cottonwood, mesquite, and saltcedar trees.

Four species are mostly or totally aquatic along the lower Colorado River. Only one of these species, Sonoran mud turtle (Kinosternon sonoriense), is apparently native; however, see Vitt and Ohmart (1978) and Stebbins (1985). This species is presently very rare. Reports of yellow mud turtle (K. flavescens) are now referred to Sonoran mud turtle (Vitt and Ohmart 1978; Stebbins 1985). The spiny softshell is the most successful of the introduced aquatic reptiles. Tiger salamanders are often released as larvae or neotenic adults by fishermen and are locally common. American alligators also have been released into the lower Colorado River system on at least two occasions since 1938, with reports of specimens into the mid-1950's (Glaser 1970).

Many of the species using sandy substrate are also upland desert species. In addition, the desert tortoise (*Gopherus agassizii*), long-tailed brush lizard (*Urosaurus graciosus*), desert night lizard (*Xantusia visilis*), and Gila monster (*Heloderma suspectum*) are upland desert species which are found in the lower Colorado River Valley proper. Most of these species occur where large washes enter the system. Desert night lizards are restricted to Joshua trees found in the Mohave Desert region in the northern portion of the lower Colorado River Valley. Desert tortoise and Gila monster are rarely encountered in the valley proper, although they are both encountered frequently in the nearby uplands. One Gila monster was reported from a cotton field near Parker (Anderson and Ohmart 1982a). The arboreal long-tailed brush lizard is very common in wide vegetated washes, whereas populations along the river are reduced in numbers.

At least 17 species are known to use agricultural-residential habitats that include aquatic and sandy situations. Some species have apparently increased with agricultural development, including the Great Plains toad (*Bufo cognatus*), Woodhouse's toad (*B. woodhousei*), bullfrog, spiny softshelled, western whiptail (*Cnemidophorus tigris*), western blind snake (*Leptophlops humulis*), and long-nosed snake (Vitt and Ohmart 1978; Anderson and Ohmart 1982a). Most of these species depend on either a predictable water supply (canals and irrigated fields) for breeding or on concentrated prey items (e.g., brushy borders with insects for whiptails). Other species found frequently in agricultural areas include Couch's spadefoot toad (*Scaphiopus couchii*), Sonoran Desert (Colorado River) toad (*Bufo alvarius*), desert iguana, side-blotched lizard (*Uta stansburiana*), desert spiny lizard (*Sceloperus magister*), coachwhip snake (*Masticophis flagellum*), gopher snake (*Pituophis melanoleucus*), and western diamondback rattlesnake (*Crotalus atrox*).

Many of the species considered to be habitat generalists are also those commonly found in man-influenced habitats. Species considered habitat generalists are Great Plains toad, Woodhouse's toad, banded gecko (*Coleonyx variegatus*), side-blotched lizard, long-tailed brush lizard, desert spiny lizard, western whiptail, ground snake (*Sonora semianulata*), coachwhip snake, gopher snake, western patchnosed snake (*Salvadora hexalepis*), common kingsnake (*Lampropeltis getulus*), spotted night snake (*Hypsiglena torquata*), and western diamondback rattlesnake.

Several species of the local herpetofauna have not been adversely affected by recreational, residential, and agricultural development along the river. Some species are actually more abundant in these situations than in native habitats. However, these species tend to be widespread and habitat generalists throughout a large geographic area. Many of the riparian and otherwise local herpetofauna endemic to the lower Colorado River have been extirpated, localized, or threatened with extirpation (Vitt and Ohmart 1978). Factors contributing to this include habitat destruction, through such activities as recreational development (especially off-road vehicles in sandy areas), overuse by tourists, and introductions of predatory species, such as bullfrog. Habitat modification attributed to overgrazing by large herbivores, such as cattle, horses, and wild burros may also affect herpetofaunal populations (Vitt and Ohmart 1978).

10.2 INTERRELATIONSHIPS AMONG THE HERPETOFAUNA AND THEIR HABITAT USE

Only one study on the lower Colorado River has been conducted to define habitat variables attracting various species of reptiles and amphibians. Herpetofaunal response to habitat as it developed from revegetating a 30-ha (75-acre) barren dredge spoil was monitored in 1980 by Anderson and Ohmart (1982b). One species of frog, three species of toads, eight species of lizards, and eight species of snakes were found using the revegetation site as the habitat developed (Table 48). Frogs and toads were associated mostly with standing irrigation water around trees or around leaks in the irrigation system. The majority of lizard and snake species were either attracted to sandy substrate with vegetation cover or were broad generalists in habitat use.

Three species were most often caught in pitfall traps. Data describing substrate and vegetation around each pitfall trap delineated habitat preferences (Figure 34). Zebra-tailed lizard was the most often encountered species and was strongly associated with sandy substrate under cottonwood trees for shade, and Russian thistle (*Salsola iberica*) for cover; the zebra-tailed lizard was the most specialized common species. Western whiptail was the second most often encountered species and was closely associated with densities of Russian thistle and arrowweed and overall foliage density below 0.6 m (2 ft); dense brush, grass, and areas of open sand were avoided, but the species was often found at the margins of these habitats. Side-blotched lizard was the most general of the three commonly encountered species but occurred in relatively lower densities; this species was found in 93% of the available habitat.

Other species frequently observed included the arboreal long-tailed brush lizard, desert iguana in open areas with sand, leopard lizard, desert spiny lizard, and banded gecko. Coachwhip, gopher snakes, and western diamondback rattlesnakes were more frequently encountered as dredge-spoil vegetation matured. Some other

Table 48. Reptiles and amphibians found on the dredge-spoil revegetation site.

Amphibians	Lizards	Snakes
Colorado River toad	Banded gecko	Coachwhip
Couch's spadefoot toad	Desert iguana	Common kingsnake
Great Plains toad	Desert spiny lizard	Glossy snake
Bullfrog	Longnosed leopard lizard	Gopher snake
	Side-blotched lizard	Sidewinder
	Western whiptail	Western diamondback rattlesnake
	Zebra-tailed lizard	Western groundsnake
		Western shovelnosed snake

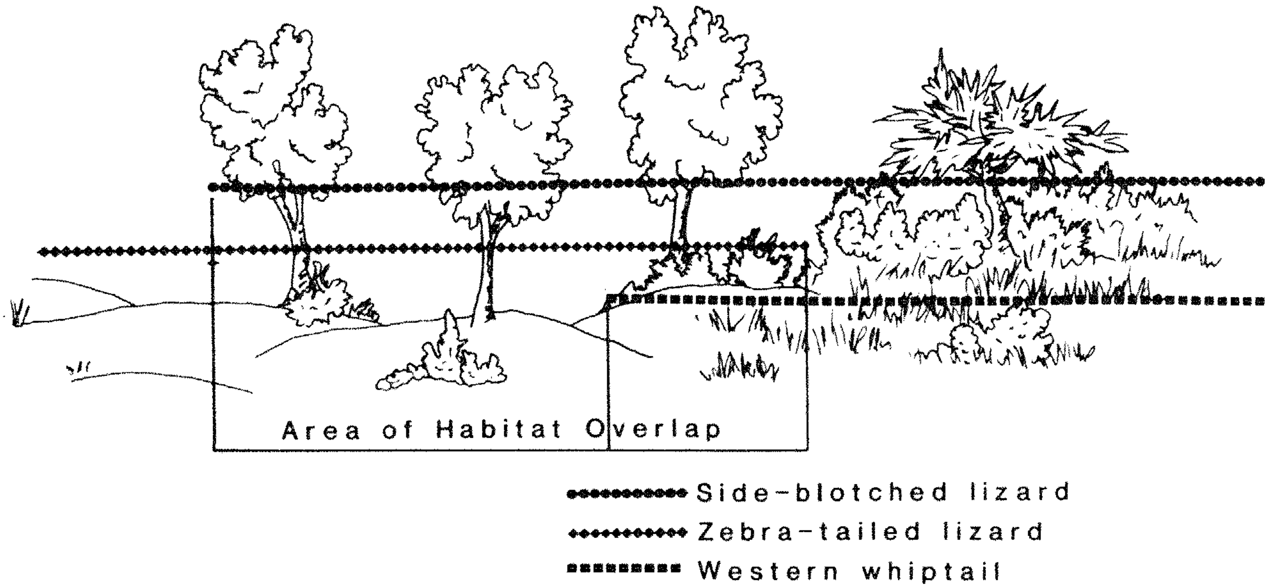

Figure 34. Diagram showing habitat overlap between side-blotched lizard, zebra-tailed lizard, and western whiptail. Adapted from Anderson and Ohmart (1982b).

species of interest found on the dredge spoil after revegetation included sidewinder (Crotalus cerestes), western ground snake, and western shovelnosed snake (Chionactis occipitalis); all species associated with sandy soil.

As with data concerning habitat associations, data for species-species interactions are few. Many of the snakes and some of the larger lizards are predatory on smaller reptiles and amphibians. In addition, the bullfrog (introduced around 1900) is highly predatory on larvae and smaller adults of other amphibians; this species has been implicated in the decline and disappearance of leopard frogs and other small frog species throughout Arizona (Haskell 1956; Clarkson and deVos 1986). Among food items found in bullfrog stomachs (Clarkson and deVos 1986) between Laguna and Morelos Dams were young muskrat, western diamondback rattlesnake, Yuma king-snake, spiny soft-shelled, several fish species, an Asiatic clam, a scorpion, and many beetles; predominant items were crayfish, wolf spiders (Lycosidae), earwigs (Labiduridae), and sowbugs (Oniscidae).

Possible competitive interactions may exist between some lizard species. Ornate tree lizards on the lower Colorado River remain restricted to large mesquites and cottonwoods, usually within 100 m (328 ft) of the river. This species does not occur in more xeric habitats where it is replaced by the usually arboreal long-tailed brush lizard and it does not occur on the ground where the ecologically and morphologically similar side-blotched lizard and juvenile desert spiny lizards are abundant. Possible climatic conditions prohibit ornate tree lizards from occurring in the latter situations, although they also may not be able to compete with other species (Vitt et al. 1981).

10.3 LISTED SPECIES AND SPECIES OF SPECIAL INTEREST

At present, there are no Federal listed endangered or threatened reptiles and amphibians commonly occurring on the lower Colorado River. However, the desert tortoise and Gila monster occur sporadically in the valley. There are however, many State-listed species or species of special interest within the river valley. These species can be divided into two groups: (1) riparian-aquatic species and (2) sand-dune obligate species.

Six riparian and aquatic species are now rare, very rare, or extirpated along the river. The southwestern toad reportedly occurs in the vicinity of Fort Mohave and small adjacent areas in California and southern Nevada; the present status of this population is unknown. An isolated population of the Pacific treefrog occurs in the extreme southern part of Clark County, NV, and in adjacent portions of San Bernadino County, CA, and Mohave County, AZ; the present status of this population is unknown, although predation by bullfrog and extensive destruction of riparian habitat is thought to have severely reduced population size of the species. The lowland leopard frog has suffered drastic declines since the 1950's along the entire system where they were abundant at the turn of the century, with bullfrogs and riparian habitat destruction usually given as primary causes. The presence of Rio Grande leopard frog, presumably introduced as bait in the 1980's, coincided with large bullfrog populations from the Gila-Colorado River confluence south to the International Boundary (Clarkson and Rorabaugh, unpubl. MS). Riparian habitat destruction and changes in aquatic habitats have also affected the Sonoran mud turtle. The extent of population declines is presently unknown along the lower Colorado River, but steep declines have been noted elsewhere in Arizona where similar habitat modifications have occurred (e.g., Lake Pleasant; Lowe 1985; Stebbins 1985; Rosen and Schwalbe, pers. comm.). Finally, both Mexican and checkered garter snakes are now very rare along the lower Colorado River, again, probably due to extensive modification of riparian habitat. Most historical records were from Blythe south to the Yuma area for both species, although there is one specimen record for Mexican garter snake from Fort Mohave (Rosen and Schwalbe 1988). Both garter snake species are declining throughout the Southwest. This decline is associated with riparian habitat modifications, with the Mexican garter snake incurring the most serious declines (Rosen and Schwalbe 1988).

Three species are considered sand-dune obligates and are primarily restricted within the confines of the lower Colorado River and adjacent desert habitats. The Colorado Desert and Mohave fringe-toed lizards and flat-tailed horned lizard appear to have stable populations wherever suitable habitat exists. However, land-use practices, primarily all-terrain vehicle use and conversion of habitat into agricultural production, may become serious threats to these populations in the near future.

Reptiles and amphibians in need of protection basically fall into the same groups as other faunal groups. Riparian and aquatic species have suffered the most severe population declines and extirpations along the lower Colorado River. In addition, locally occurring sand dune-obligate species need to be monitored, especially in areas where incompatible land uses are expected to increase.

CHAPTER 11. AVIAN COMMUNITIES

Each major aquatic and terrestrial habitat supports a relatively distinct assemblage of bird species. These species occur at somewhat predictable numbers among habitats from year to year and from season to season. At present, about 400 species of birds have been recorded on the lower Colorado River (Appendix B). Within each habitat, bird species composition and abundance varies seasonally according to the specific foraging and nest sites available, food resource levels, and the seasonal status of the birds. Below we discuss major riparian, desert, agricultural, and aquatic habitats and their associated avifauna. Bird community dynamics are treated in detail in several reports, many papers, and an upcoming book (Anderson and Ohmart 1982a,b, 1984b; Rosenberg et al., in prep.). All statements are supported in these documents unless cited otherwise.

11.1 COTTONWOOD-WILLOW

The cottonwood-willow association was characteristic of the Colorado River Valley before settlement and into the early 1900's. Although this habitat is now significantly reduced in area, it remains vital to a key segment of the region's avifauna. In terms of bird abundance and variety, mature cottonwood-willow groves are among the richest habitats in North America.

Numerous migratory birds that either breed or winter in the Colorado River Valley prefer the tall willows and cottonwoods over shorter or shrubby vegetation. These seasonal residents are largely responsible for the high diversity of birds in this habitat. Summer breeding birds, such as yellow-billed cuckoos (Coccyzus americanus), willow flycatcher (Empidonax traillii), vermilion flycatcher (Pyrocephalus rubinus), brown-crested flycatcher (Myiarchus tyrannulus), yellow warbler (Dendroica petechia), and summer tanagers (Piranga rubra), are largely restricted to native cottonwood-willow stands; others, such as Bell's vireos (Vireo bellii), yellow-breasted chats (Icteria virens), and northern orioles (Icterus galbula), attain their highest densities in these habitats. Three permanent resident primary cavity-nesting species, gilded northern flickers (Colaptes auratus mearnsi), ladder-backed woodpeckers (Picoides scalaris), and Gila woodpeckers (Melanerpes uropygialis), also reach their highest numbers throughout the year in this habitat type, as does the ground-dwelling Abert's towhee (Pipilo aberti). Today, this assemblage of birds can be found together only at the Bill Williams Delta; the last stronghold for what Grinnell (1914) noted as the most conspicuous element of the valley's avifauna.

Outside of the breeding season, the Bill Williams' cottonwood-willow groves continue to attract a changing variety of abundant bird species. As the summer breeding species depart in August and September, common migrant tanagers, grosbeaks, flycatchers, vireos, and warbers take their place.

By late fall, large flocks of yellow-rumped warblers (Dendroica coronata), orange-crowned warblers (Vermivora celata), and ruby-crowned kinglets (Regulus calendula) move throughout the forest canopy consuming aphids, leafhoppers, and other small insects. At the same time, in the understory composed of saltcedar, dead branches, and wet leaf litter, house (Troglodytes aedon), Bewick's (Thryomanes bewickii), and marsh (Cistothorus palustris) wrens occur in abundance, along with lower numbers of hermit thrushes (Catharus guttatus) and rufous-sided towhees (Pipilo erythropthalmus).

All these species remain common through the winter, unless an infrequent cold snap causes the trees to shed their leaves and insect populations to decline. In late January, when cottonwoods bloom, warblers and other insectivores flock to these trees to feed on nectar and insects attracted to the flowers. They are joined by flocks of lesser goldfinches (Carduelis psaltria), usually mixed with pine siskins (C. pinus), and low numbers of American (C. tristis) or Lawrence's (C. lawrencei) goldfinches. A month later, the willows begin to bloom, and, accordingly, the feeding flocks move to willows. By mid-March, trees are fully leafed as spring arrival of ash-throated flycatcher (Myiarchus cinerascens), Lucy's warbler (Vermivora luciae), and northern oriole begins. Besides this progression of seasonal residents and migrants, several uncommon wintering species are found regularly only in the tall cottonwoods and willows. These include red-breasted sapsucker (Sphyrapicus ruber), brown creeper (Certhia americana), and winter wren (Troglodytes troglodytes).

Remaining tracts of willows or cottonwoods outside of the Bill Williams Delta attract portions of these species assemblages depending on the maturity of the trees, size of the grove, and amount of saltcedar and shrubs present. Even sparse and isolated willow patches, however, are better habitats for birds than are pure saltcedar or sparse, stunted mesquite stands.

One important feature that separates mature cottonwood-willow habitats from other riparian vegetation is their structural complexity. Cottonwoods and willows typically grow to be the tallest trees in the valley, often up to 21 to 24 m (70 to 80 ft), thus providing both vertical and horizontal foliage layers often absent in other riparian habitats. Foliage diversity has been shown repeatedly to be correlated with higher numbers of bird species. On the lower Colorado River such structural complexity also allows for additional cover from the extreme summer temperatures that may otherwise interfere with the nesting of many midsummer breeding species (Hunter et al. 1985, 1987).

Small stands of tall, mature cottonwood are important to roosting and nesting herons, egrets, and large raptors. Presently, no large raptors are known to nest in riparian habitats. Historically, however, Harris' hawks (Parabuteo unicinctus) were known to nest on the Colorado River and may soon again with reintroduction efforts. Cooper's hawks (Accipiter cooperii) and zone-tailed hawks (Buteo albonotatus) may have nested into the early twentieth century but probably were never common. Finally, common black-hawk (Buteogallus anthracinus) occurs occasionally on the Bill Williams River but has never been known to nest within the confines of the lower Colorado River, even though a stable breeding population exists on the nearby Big Sandy drainage. The few nesting egret and heron colonies are all threatened from disturbance and removal of nesting trees, with little hope of replacement.

11.2 HONEY MESQUITE

Honey mesquite habitats along the Colorado River rank second to cottonwood-willow in terms of bird abundance and variety. Unlike the seasonal progression of bird species described above, the honey mesquite community is dominated for much of the year by permanent resident insectivores such as crissal thrashers (Toxostoma crissale), cactus wrens (Campylorhynchus brunneicapillus), verdins (Auriparus flaviceps), and black-tailed gnatcatchers (Polioptila melanura). In addition, ash-throated flycatchers reach their highest densities in honey mesquite, although this species is generally absent from the valley in midwinter. One notable seasonal resident, Lucy's warbler, arrives in numbers just as mesquites leaf out and blossom in mid-March. Very high breeding densities can be found in optimum habitats for this warbler during April and May, with each pair attempting to raise one brood. Most Lucy's warblers depart by mid-July. Most other birds in honey mesquite also nest early, but permanent residents generally raise multiple broods and continue breeding through early summer.

Gambel's quail (Callipepla gambelii) maintain their highest winter and spring breeding populations in honey mesquite habitats where they feed on both mesquite seeds and abundant desert annuals. A few other typical desert species, such as loggerhead shrike (Lanius ludovicianus) and black-throated sparrow (Amphispiza bilineata), are widely dispersed through sparse mesquite woodlands, while avoiding denser riparian vegetation.

Two botanical features found in honey mesquite stands attract seasonal residents and add greatly to the overall composition of the bird community. One feature is mistletoe, which parasitizes honey mesquite more than other tree species in the area. Mistletoe clumps produce large amounts of berries that support a huge wintering population of phainopeplas (Phainopepla nitens). The phainopepla is highly adapted for feeding almost exclusively on mistletoe berries during winter. This silky flycatcher is unique among the valley's birds in that it begins breeding in late winter and migrates out of the valley in May. Other frugivorous birds attracted to the mistletoe-infested mesquite woods in winter include small flocks of cedar waxwing (Bombycilla cedrorum), American robin (Turdus migratorius), and western (Sialia mexicana) and mountain (S. curricoides) bluebirds. In addition, small numbers of sage thrasher (Oreoscoptes montanus) arrive in February and March, at which time lone birds will take up temporary residence at individual mistletoe clumps. The northern mockingbird (Mimus polyglottos) is the only permanent resident that feeds heavily on mistletoe, although Gambel's quail, Gila woodpecker, and house finch (Carpodacus mexicanus) occasionally consume berries.

The second important feature of honey mesquite habitats is the presence of several shrub species that form large patches in more open stands. Quail bush and salt bush are most common, providing perennial foliage for small wintering insectivores, such as verdins, gnatcatchers, and orange-crowned warblers. These shrubs also provide abundant food and cover for wintering granivores. Large, roving flocks of white-crowned sparrows (Zonotrichia leucophrys) predominate, often mixed with smaller numbers of dark-eyed juncos (Junco hyemalis) and Brewer's (Spizella breweri) and chipping (S. passerina) sparrows. Resident Gambel's quail and Abert's towhees feed and take refuge in these shrubby patches as well. Another shrub, inkweed, is found in only a few parts of the valley (north of Ehrenberg and east of Poston), but sage sparrows (Amphispiza belli) are common during winter months where it grows.

11.3 HONEY MESQUITE-SALTCEDAR MIX

Honey mesquite generally dominates on upper floodplain terraces. This leguminous plant is frequently the only riparian tree to form monotypic stands, in which saltcedar is not an important component. However, a mixture of honey mesquite and saltcedar occurs rather locally in the vicinity of Cibola National Wildlife Refuge and on the Fort Mohave Indian Reservation. This mixed tree community supports avian species not found in pure saltcedar or pure honey mesquite stands. Saltcedar forms a dense understory in these stands and adds significantly to summer insect production. Conversely, honey mesquite offers accessible foraging sites, along with a well-developed, but patchy canopy layer.

An interesting bird species not found in pure stands of honey mesquite or saltcedar is Bell's vireo, which historically was most highly associated with willow-dominated habitats. Although Bell's vireo is now rare on the lower Colorado River and does not occur in all honey (or even most) mesquite-saltcedar stands, this vegetation type represents its most important habitat outside the willow stands of the Bill Williams Delta and near Needles. Similarly, yellow-breasted chat, outside the Bill Williams River, reaches its highest densities in these mixed communities on the lower Colorado River and is rarely encountered in pure stands of either saltcedar or honey mesquite.

Both the chat and vireo were once abundant along the lower Colorado River and were two of the five species that Grinnell (1914) considered characteristic of the willow-cottonwood association. These two species seem to require both a dense understory and, at least, a moderately tall canopy layer. The fact that a honey mesquite-saltcedar mix is apparently adequate for these two summer visiting insectivores illustrates the importance of vegetation structure alone in determining the habitat preferences of certain bird species.

11.4 SCREWBEAN MESQUITE-SALTCEDAR MIX

On the lower Colorado River, all screwbean mesquite stands are mixed with saltcedar. In contrast to honey mesquite, screwbean mesquite is rarely parasitized by mistletoe and grows so dense that few shrubs become established. Screwbean mesquites generally grow taller than honey mesquites, and because they occur closer to the river bank, screwbean mesquite groves often contain a few isolated cottonwoods and willows. For much of the year, the bird community in screwbean mesquite habitats is composed almost entirely of permanent resident species. The general lack of perennial foliage, fruit, or seeds makes these areas among the least attractive of riparian habitats for winter resident warblers, sparrows, and frugivores. However, in summer, some gilded northern flickers, Gila woodpeckers, ash-throated and brown-crested flycatchers, and a few Bell's vireos, yellow-breasted chats, and yellow-billed cuckoos are attracted to the tall canopy and scattered cottonwoods. Lucy's warblers are common in screwbean mesquite-dominated stands.

Perhaps the most conspicuous avian feature of mature screwbean mesquite-saltcedar habitats is their tremendous density of nesting white-winged (*Zenaida asiatica*) and mourning (*Z. macoura*) doves. These birds may place their loosely constructed nests as close as 1 m (3 ft) from one another throughout the dense canopy, and the din of their calls at first light is deafening. In addition, during late summer and fall the seed pods of the screwbean mesquite ripen and fall, providing an abundant food source for many wildlife species. In particular, large coveys of Gambel's quail move into these woods from other riparian and desert areas to feed on these seeds.

Screwbean mesquite habitats have increased in area with the stabilization and channelization of the river. Grinnell (1914) found screwbean mesquite primarily where the river bed was very old or where backwaters had formed. At present, since cottonwoods and willows are not naturally regenerating, screwbean mesquite, in association with saltcedar, is becoming more prevalent. Structurally well-developed stands of screwbean mesquite, however, are continuously under threat of clearing or as individual screwbean trees die they are replaced by saltcedar to slowly become monocultures.

11.5 ARROWWEED

Arrowweed is a shrub, generally 1.8-2 m (6-8 ft) tall that frequently occurs in monotypic stands. Their single, vertical stems grow very close together, making the stands almost impenetrable. These stands attract only a few ground-foraging residents, such as mourning doves, Gambel's quail, and Abert's towhees, as well as a few verdins, blue grosbeaks (*Guiraca caerulea*), and wintering sparrows. Other species will occasionally forage in arrowweed if trees are available nearby.

Interestingly, Grinnell (1914) commented on the extensive tracts of arrowweed that formed the perimeters of many willow groves and stated that they were the first plants to colonize the recently created silt beds and shoals. At that time, the only resident bird reaching peak abundance in arrowweed was the desert race of the song sparrow (*Melospiza melodia*). Today, resident song sparrows are rarely found outside of marshes, except in partially flooded willows or saltcedar.

11.6 SALTCEDAR

At all times of the year, monocultures of exotic saltcedar support the lowest densities and varieties of bird species of any riparian habitat except arrowweed. Most saltcedar stands are of short stature (<4.6 m [<15 ft] tall) and are very dense. Bird species that occur in these habitats are generally permanent resident ground-foragers or small insectivores; cavity-nesting woodpeckers and flycatchers are absent. Frugivores are virtually absent in saltcedar habitats. Among the valley's summer residents, only mourning and white-winged doves, Lucy's warblers, blue grosbeaks, and brown-headed cowbirds (*Molothrus ater*) do not seem to avoid pure saltcedar habitat. These habitats are largely devoid of birds in winter.

Several factors probably contribute to the scarcity of birds in saltcedar. Although insects are often abundant in saltcedar during summer, the trees produce a sticky and salty exudate that may inhibit birds from foraging efficiently in the dense foliage. Since many insectivores do nest and feed in saltcedar in other river valleys farther east, the absence of these birds in saltcedar on the lower Colorado River may be more complex than the mere inability to cope with the sticky exudate. Summer temperatures become more severe from east to west across the Southwestern deserts, and certain migratory mid-summer breeding birds become more specialized in their use of multi-layered habitats such as cottonwood-willow (Hunter et al. 1985; Hunter 1987). Perhaps for these birds, the shrubby saltcedar cannot mitigate against the extreme summer heat; farther east the more moderate summer environment allows these same species a greater flexibility in their use of lower-statured habitats.

Notable exceptions to these generalizations are the occasional saltcedar stands that are spared from fire long enough to attain heights 8 to 9 m (26 to 30 ft), and also stands of vegetatively reproducing athel tamarisk (Tamarix aphylla) >20 m (>66 ft). Although rare, these mature saltcedar groves can nearly equal native vegetation in their value to some breeding birds. White-winged and mourning doves nest abundantly, and these areas attract such uncommon summer residents as black-chinned hummingbirds (Archilochus alexandri), yellow-breasted chats, and summer tanagers. Ironically, after a saltcedar stand burns, it is also temporarily more attractive to birds. Opening of the canopy and presence of numerous dead snags, as well as the continual emergence of summer insects (such as the cicada), attract large numbers of many birds that are not normally found in saltcedar. These birds include aerial-foraging western kingbirds (Tyrannus verticalis) and lesser nighthawks (Chordeiles acutipennis), as well as the recently invading indigo bunting (Passerina cyanea).

As noted above, saltcedar frequently occurs mixed with native riparian vegetation, especially willows and screwbean mesquite. Birds found in these areas are generally determined by the dominant native tree species, and the effect of saltcedar in the understory is usually negative. In contrast, even a few native trees or patches of native shrubs (e.g., salt bush) scattered through a saltcedar stand will greatly enhance the area's value to birds.

11.7 DESERT WASHES

The combination of tall trees and low-growing vegetation attracts a diverse blend of desert and riparian bird species. The bird community is basically similar to that in honey mesquite habitats, including all the frugivores and wintering sparrow species. However, a few desert specialists such as Costa's hummingbirds (Calypte costae) and black-throated sparrows (Amphispiza bilineata) are more numerous in these desert washes. A few riparian species (Crissal thrasher and Abert's towhee) also use these washes. Where saguaros are present, the full complement of cavity-nesting species may be found far from their more typical lush cottonwood-willow habitats. This observation clearly illustrates how a single critical resource, such as nest cavities, will determine the distribution of a bird species or group of species.

11.8 MARSHES

As noted earlier, marshes and other aquatic habitats have become an important component of the valley's wildlife habitats after the construction of large impoundments. Like terrestrial riparian habitats, present-day marshes vary in plant species composition and vegetation structure, as well as proximity to adjacent open water or trees. In general, marshes, dominated by dense cattails or bulrushes, support large numbers of breeding insectivores, rails, least bitterns (Ixobrychis exilis), and other waders (Anderson et al. 1984) (Table 49). Most of these species, however, can be found in almost any marshy situation along the river. Marshes composed mostly of cane or reed attract the fewest birds of any marsh type.

Nonbreeding birds, primarily wintering waterfowl, migratory shorebirds, and dispersing waders, prefer more open marshes, especially those where mudflats and sandbars are exposed (Anderson et al. 1984). Where riparian trees are interspersed with marsh vegetation, a number of other birds are added to the community; these trees also act as roosting or nesting places for herons and egrets. Heron and egret nesting colonies are of special concern to all wildlife agencies. Water management activities are often proximal to those colonies and may severely inhibit successful breeding.

Artificial marshes behind backwater levees and jetties compare favorably for wildlife with more natural marshes. Marshes tend to evolve either slowly or rapidly from hydric (i.e., wet conditions) to xeric (i.e., dry conditions). Without management toward hydric conditions these areas lose their attractiveness to birds. Increased channelization of the river will result in a decrease in marsh habitats because higher, swifter flows deepen the river channel and prevent the growth of emergent plants. Deepening of the channel also lowers the adjacent water table, effectively drying wet or marshy areas. Ironically, the marsh bird community, which has enjoyed more extensive and stable habitats since historical times, is now perhaps the most susceptible to immediate danger from river management activities. The following subsection covers two endemic marsh species found on the lower Colorado River.

Threatened Marsh Birds

Two species of rails are particularly threatened by water management activities on the lower Colorado River. The black rail is presently a candidate for Federal listing and the Colorado River population is completely isolated from all other conspecific populations. The only endemic bird listed with Federal endangered status on the lower Colorado River is the Yuma clapper rail. These two species are of special concern to management agencies, and their known biological attributes are summarized below.

Black rail. Black rails were first found during 1969 in small numbers around the Imperial Dam area. Total population size is now estimated at about 200 individuals from Mittry Lake north to Imperial National Wildlife Refuge. More recently, up to 10 individuals have been found in the Bill Williams Delta (since 1979), and about the same number have been found since the mid-1970's along the Coachella and Highline Canals near Niland, CA. Status of the species along the Colorado River in Mexico is not known presently.

Very little specific data is available on the biology of the black rail on the lower Colorado River. This very secretive species is detected almost exclusively in marshes containing large mats of three-square bulrush. This emergent plant rarely grows taller than 1 m (3 ft), and the black rail seems to prefer stable water levels of a few centimeters or less (Repking and Ohmart 1977).

Table 49. Seasonal breakdown of guilds in each marsh type. Type I = nearly 100% cattail/bulrush, small amounts of cane and open water; Type II = nearly 75% cattail/bulrush, many trees and grasses interspersed; Type III = about 25%-50% cattail/bulrush, some cane, open water, some trees and grasses; Type IV = about 35%-50% cattail/bulrush, many trees and grasses interspersed; Type V = about 50%-75% cattail/bulrush, few trees and grasses interspersed; Type VI = nearly 100% cane, little open water; Type VII = open marsh (75% water), adjacent to sparse marsh vegetation, includes sandbars and mudflats when Colorado River is low; and Type VIII = Topock Marsh, near Needles, CA, vegetation similar to Type I, but with even denser stands of bulrushes. Type VIII was kept separate for purposes of analysis as it was censused for only five months and is geographically isolated from the rest of the study area. L summer = late summer. X = not censused. Adapted from Anderson et al. (1984).

		Birds/40 ha (100 acres)					
Marsh type	Season	Wading birds	Water-birds	Shore-birds	Permanent resident insectivores	Visiting insectivores	Granivores
I	Winter	10	119	1	41	112	47
	Spring	21	59	1	36	115	42
	Summer	39	30	1	52	144	56
	L summer	13	61	0	27	90	40
	Fall	29	50	1	42	138	106
II	Winter	7	115	2	105	302	251
	Spring	17	165	9	51	143	129
	Summer	22	44	3	115	76	43
	L summer	30	53	5	35	48	52
	Fall	10	46	1	52	232	307
III	Winter	3	161	15	190	166	195
	Spring	8	173	17	127	105	111
	Summer	32	71	3	187	103	50
	L summer	26	45	8	151	113	65
	Fall	3	75	16	178	163	130
IV	Winter	8	145	9	52	174	152
	Spring	7	155	27	30	94	61
	Summer	12	67	2	80	63	66
	L summer	19	56	14	73	87	79
	Fall	20	34	25	51	170	205
V	Winter	13	14	2	37	97	56
	Spring	31	16	1	94	114	31

(Continued)

Table 49. (Concluded)

Marsh type	Season	Birds/40 ha (100 acres) Wading birds	Water-birds	Shore-birds	Permanent resident insectivores	Visiting insectivores	Granivores
V (Cont.)							
	Summer	47	8	0	94	112	16
	L summer	44	10	0	44	111	23
	Fall	20	15	1	49	167	47
VI	Winter	15	18	0	10	181	9
	Spring	34	8	0	6	189	13
	Summer	36	6	0	6	82	45
	L summer	39	9	0	0	179	0
	Fall	4	11	0	0	88	0
VII	Winter	5	294	76	69	170	102
	Spring	5	234	73	35	165	57
	Summer	18	38	8	77	59	33
	L summer	14	43	64	105	63	29
	Fall	6	133	105	78	122	83
VIII	Winter	X	X	X	X	X	X
	Spring	16	114	0	59	181	13
	Summer	43	53	0	4	238	11
	L summer	X	X	X	X	X	X
	Fall	X	X	X	X	X	X

Black rails are one of the most difficult birds to observe in North America, but like all rails, they are quite vocal. Peak calling activity is in spring and early summer, although at least a few individuals are found calling year-round. Very little is known, however, about this population's migratory habitats (if there are any). Recent population expansions north to the Bill Williams River suggest that at least some birds disperse relatively far.

Yuma clapper rail. The Yuma clapper rail has experienced an interesting history on the lower Colorado River. The first specimen was collected in 1902 near Yuma, but the subspecies was not described until additional specimens were taken in 1921 and 1924 (Swarth 1914; Dickey 1923). Marsh vegetation was not extensive during this period, north of the Gila River confluence (Grinnell 1914). Thus, tracking the development of extensive marshes behind major dams is interesting with respect to a concomitant expansion of the Yuma clapper rail on the lower Colorado River.

The water levels in 1921 and 1924 were above average and, with the additional effects from Laguna Dam (closed in 1909), extensive development of cattails was spurred in the canals where the first Yuma clapper rails were collected. The discovery of this subspecies north of Laguna Dam followed some years after the completion of Parker, Imperial, and Headgate Rock Dams in 1938, 1939, and 1942, respectively. The first sightings of Yuma clapper rail in the Bill Williams Delta by Gale Monson on 12 May 1954 was 16 years after the completion of Parker Dam; Monson had visited the area regularly on an annual basis before the 1954 observation. Reports from Topock Marsh did not occur until 1966, and this area now supports a large northerly population center. Laughlin Lagoon represents the northernmost reliable location for Yuma clapper rails at present. Recent expansions into the newly formed Salton Sea by the 1940's and Picacho Reservoir in central Arizona by the 1970's support the view that the Yuma clapper rail is highly vagile. Presently, most researchers believe the population's distribution was restricted to the Colorado River Delta, with some individuals dispersing north in search of suitable habitat along the river during very high flow years (Ohmart et al. 1975; Monson and Phillips 1981; for an opposing view see Todd 1987). The construction of dams, which have so altered much of the river's dynamic nature, also served to stabilize marshes and increase suitable nesting habitat for Yuma clapper rails (Ohmart et al. 1975).

The introduction of craytish in the early 1900's undoubtedly contributed to the range expansion of Yuma clapper rail. Crayfish appear to be the most important food item in the rail's diet. Therefore, crayfish abundance and activity patterns may seriously limit Yuma clapper rail seasonal and spatial occurrence along the Colorado River and in adjacent drainages (Ohmart and Tomlinson 1977). Other foods taken by Yuma clapper rail include isopods, beetles, damselfly nymphs, grasshoppers, spiders, and Asiatic clams.

Nesting behavior commences as early as February, with most eggs hatching by the first week of June, although the season may extend into July. As with many precocial birds with large clutches (6-8), young Yuma clapper rails are highly susceptible to depredation by other marsh animals. Other details on breeding may be found in Smith (1975) and Bennett and Ohmart (1978).

Yuma clapper rails are associated primarily with very dense marsh vegetation, but high densities may be found also in some moderately dense cattail/bulrush marshes. This rail may also occur in dense cane and even sparse cattail/bulrush marshes, but in much reduced numbers (Anderson and Ohmart 1985a). Until recently, Yuma clapper rails were thought to be mostly migratory, with few individuals remaining to winter in the lower reaches of the valley. Recent increases in detections on the Martinez Lake-Yuma Christmas Bird Count since the early 1970's and radiotelemetry work during the mid-1980's indicate that a high proportion of the Yuma clapper rail population now may be overwintering (Eddleman et al. 1987).

Yuma clapper rail population size on the lower Colorado River is estimated to be between 400 and 750 in the United States, with 400-500 in Mexico (Eddleman et al. 1987). Despite the apparent increases since the

1920's, the present population size remains low and is limited by and has come under the threat of reduction from other river management activities. Dredging, channelization, and stabilizing banks by riprapping are all detrimental to marsh habitat formation. Recent flooding has resulted in greater pressure on water management agencies to increase channelization and bank stabilization activities, which will result in further reductions in available marsh habitat. These actions, in turn, may severely reduce the Yuma clapper rail population.

11.9 OPEN WATER

Surveys of open water habitats confirmed the increased value of the lower Colorado River for waterbirds since river management began (Table 50) (Brown 1985; Anderson and Ohmart 1988). Whereas Grinnell (1914) recorded only a few ducks and coots along the entire river in 1910, at least 10 species of waterfowl, as well as American coots (Fulica americana) and several species of grebes, can be considered common to abundant during winter. Waterbirds typically associated with oceanic or other deep-water habitats have probably benefited the most. We have recorded loons, western and eared (Podiceps nigricollis) grebes, goldeneye, bufflehead, mergansers, ring-billed gulls (Larus delawarensis), and sometimes California gulls (L. californicus) as common only on large lakes and in the deep channels immediately below dams. On the other hand, puddle ducks, pied-billed grebes (Podilymbus podiceps), and American coots are most numerous in unchannelized stretches and in shallow backwaters that support emergent and submerged vegetation. The year-to-year abundance of several duck species, including gadwall (Anas strepera), American wigeon (A. americana), and redhead (Aythya americana), is largely determined by the local distribution of Sago pondweed beds. Sago pondweed cannot withstand swift current, so it is adversely affected by channelization or by unusually high water levels. River segments least used by birds are channelized stretches away from dams (Anderson and Ohmart 1988).

In summer, very few birds are found in open water areas. Marsh-nesting coots and grebes will venture out onto the river or lakes, and herons use the river banks for feeding year-round. Summer is the peak migration time for several species of shorebirds and terns, however. Post-breeding dispersers such as brown pelicans (Pelecanus occidentalis), boobies, or magnificent frigatebirds (Fregata magnificens) also visit the Colorado River in summer. All of these species must compete for space with recreationists that also flock to the river and lakes in summer to boat, fish, and water ski. Increased development of recreational areas along the river and the increased pressure to channelize more of the river because of recent flooding will adversely affect many waterfowl species.

11.10 AGRICULTURAL AREAS

Of all the habitat changes experienced in the lower Colorado River Valley, the conversion of vast riparian areas to agricultural production is certainly the most dramatic. Bird species using agricultural lands are generally different from those that use riparian vegetation (Table 51). In fact, of all riparian residents, only doves, western kingbirds, yellow-rumped warblers, and white-crowned and Brewer's sparrows were regularly found more than 1.3 km (0.8 mi) from riparian tracts (Table 52) (Conine et al. 1978; Anderson and Ohmart 1982a).

Table 50. Comparisons of waterfowl species seen in 1910 (Grinnell 1914) and in 1978 (Anderson and Ohmart 1988). Scientific names in Appendix B.

	Number observed	
	Grinnell	Anderson and Ohmart
Species	February-May 1910	February-May 1978
Cinnamon teal	1	207
Green-winged teal	100-400	977
Lesser scaup	100-400	116
Mallard	6	213
Northern pintail	1	149
Northern shoveler	4	37
Red-breasted merganser	23	31
Ruddy duck	4	6
American wigeon	0	620
Barrow's goldeneye	0	92
Bufflehead	0	226
Canvasback	0	3
Common goldeneye	0	1,743
Common merganser	0	591
Gadwall	0	95
Greater scaup	0	4
Redhead	0	56
Ring-necked duck	0	68
Surf scoter	0	4
Total number observed	239-839	5,218
Total species observed	8	19

Only the kingbird breeds in both agricultural and riparian situations. However, along riparian-agricultural edges, riparian bird populations appear to benefit from the combination of increased food resources (from cultivated crops) and escape and nesting cover provided proximally by trees and shrubs. In particular, roadrunners, doves, Gambel's quail, crissal thrashers, Abert's towhees, and wintering sparrows and warblers were found in high densities along these edges.

Nearly all bird species using agricultural cropland to any extent are migratory, and many of these stay through the winter months. Among the few permanent residents which breed are western meadowlarks (*Sturnella neglecta*), a small population of horned larks (*Eremophila alpestris*), a few killdeer (*Charadrius vociferus*), and burrowing owls. In addition, marsh-nesting red-winged (*Agelaius phoeniceus*) and yellow-headed (*Xanthocephalus xanthocephalus*) blackbirds rely heavily on agricultural

Table 51. Status summary of 41 terrestrial bird species in agricultural areas. Status refers to number of months present, not density. Species in each riparian community type are compared relative to agricultural areas. Numbers refer to number of species that had increased, equal or decreased status from the riparian community to agricultural areas. From Anderson and Ohmart (1982a).

Riparian community	Status: Lower in agricultural areas	Equal in agricultural areas	Higher in agricultural areas
Saltcedar	13	13	15
Honey mesquite	14	17	10
Cottonwood-willow	17	18	6
Agricultural-riparian edge	10	18	13

Table 52. Density changes of riparian bird species at their maximum distance traveled into agricultural areas from their density throughout agricultural areas. P = present and is indicated by an X, S = status, D = a drop in density at maximum distance from riparian edge. Adapted from Conine et al. (1978). Scientific names in Appendix B.

	Distance from riparian vegetation									
	0.4 km		0.8 km		1.2 km		2.0 km		2.4 km	
Species	P	S	P	S	P	S	P	S	P	S
Gambel's quail	X	D								
Mourning dove	X		X		X		X		X	D
White-winged dove	X		X		X		X		X	D
Common ground-dove	X		X		X					
Greater roadrunner	X	D								
Lesser nighthawk	X		X							
Northern flicker	X		X	D						
Black phoebe	X									
Say's phoebe	X		X		X		X		X	D
Western kingbird	X		X		X		X		X	D
Marsh wren	X		X		X		X		X	D

(Continued)

Table 52. (Concluded)

Species	Distance from riparian vegetation									
	0.4 km		0.8 km		1.2 km		2.0 km		2.4 km	
	P	S	P	S	P	S	P	S	P	S
Northern mockingbird	X		X		X		X		X	
Crissal thrasher	X									
Loggerhead shrike	X		X		X		X			
Orange-crowned warbler	X		X		X		X		X	
Yellow-rumped warbler	X		X		X		X		X	D
Blue grosbeak	X									
Abert's towhee	X									
Chipping sparrow	X		X		X	D				
Brewer's sparrow	X		X		X					
Dark-eyed junco	X		X	D						
Sage sparrow	X		X		X		X		X	
White-crowned sparrow	X		X		X		X		X	D
Lincoln's sparrow	X		X		X		X		X	
Northern oriole	X		X		X		X	D		
Brown-headed cowbird	X		X		X		X		X	D
House finch	X		X		X		X		X	D

fields for food and, occasionally, will establish breeding colonies in marshy canals or even in tall alfalfa and wheat fields. Where human residences provide tall trees and other plantings, species such as Inca dove (*Columbina inca*), western kingbird, European starling, great-tailed grackle, and house sparrow (*Passer domesticus*) are added to complete the agricultural breeding bird community.

During the nonbreeding season, the number of species in agricultural areas can be quite large. The number and kinds of birds are definitely greatest where weedy margins and dirt-lined canals are interspersed with cultivated fields. These margins attract flocks of wintering sparrows and are favorite feeding areas for Say's phoebes (*Sayornis saya*), loggerhead shrikes, and American kestrels (*Falco sparverius*). Irrigation canals are used by grebes, cormorants, ducks, and herons, and if marsh vegetation becomes established, bitterns, green-backed herons (*Butorides striatus*), rails, and marsh wrens may occur.

Among the cultivated crops, alfalfa is most attractive to a variety of birds. Western meadowlarks and savannah sparrows (*Passerculus sandwichensis*) are abundant in taller stands, and water pipits (*Anthus spinoletta*) in shorter stands. Northern harriers (*Circus cyaneus*) often hunt over these fields, and concentrations of geese or sandhill cranes (*Grus canadensis*) may also feed there. In contrast to alfalfa fields, plowed fields, cotton, and various truck crops (e.g., lettuce, onions) consistently support the fewest birds. However, plowed fields occasionally attract large flocks of horned larks or, occasionally, mountain plovers (Charadrius montanus).

When fields are irrigated, a new habitat dimension is added. A plowed and flooded field is the best place to find concentrations of migratory shorebirds, especially in late summer (Ohmart et al. 1985) (Table 53). Here too, flocks of white-faced ibis (Plegadis chihi), cattle egret (Bubulcus ibis), puddle ducks, gulls, pipits, and blackbirds congregate to feed on the insects flushed out by the irrigation water. In addition, doves, starlings, and blackbirds concentrate at feedlots or sheep pastures. Finally, recently harvested grain fields may attract geese, cranes, doves, blackbirds, sparrows and house finches.

The abundant food provided by agricultural habitats certainly benefits a wide variety of birds that use them opportunistically. Numbers of species and densities may become quite high in winter when the birds are not nesting. The future for many riparian bird species in agricultural valleys however, is not optimistic. A mosaic of native habitats among developed areas and a cessation to the removal of remaining tall trees and weedy margins will be required to protect these species.

11.11 LISTED SPECIES AND SPECIES OF SPECIAL CONCERN

Five Federally listed bird species are found on the lower Colorado River, but only one of these species is fairly common. Bald eagles (Haliaeetus leucocephalus) winter in small numbers along the entire river but concentrate on Havasu and Imperial National Wildlife Refuges. Bald eagles are known to nest along the Bill Williams River near Alamo Dam. A pair also attempted to nest near Topock in 1977 and again in 1978. Recent expansion of nesting bald eagles throughout Arizona may soon encompass the lower Colorado River. Peregrine falcons (Falco peregrinus) migrate through the river valley in some numbers. Breeding presently is known only from the Parker Dam area, but can be expected wherever steep cliffs occur adjacent to the river. Two endangered species occur only as vagrants, brown pelicans are found yearly dispersing from the Gulf of California and least terns (Sterna albifrons) occur casually, usually during summer.

The Yuma clapper rail is presently the only endangered (Federal) bird species on the lower Colorado River that is fairly common. The international population is about 1,000 individuals. Major impacts that would affect the population would come from continuous water management activities including channelization, dredging, water level fluctuation during breeding, and levee maintenance. Also, continued recreational and residential development along the river will have numerous local impacts which cumulatively may negatively affect the whole population.

On the State level, California recognizes the elf owl (Micrathene whitneyi) and yellow-billed cuckoo as endangered species and has proposed black rail, gilded northern flicker (C. a. mearnsii), Gila woodpecker, and Arizona Bell's vireo (V. b. arizonae) for State legal protection (Cardiff 1978; Serena 1986). Top priority species of special concern in California include Harris' hawk, vermilion flycatcher, willow flycatcher, Sonoran yellow warbler (D. p. sonorana), and summer tanager. Many of the above species were widespread, common, and

Table 53. Agricultural crops and features with which shorebirds were associated with a frequency greater than expected with a random distribution on transects. IR = irrigated, NI = not irrigated, > is greater 25 cm (10 inches) in height, < is less than 25 cm (10 inches) in height. From Ohmart et al. (1985). Scientific names in Appendix B.

Species	Total occurrences	Plowed IR	Plowed NI	Alfalfa <NI	Grass >IR	Grass >NI	Grass <IR	Grass <NI	Wheat >IR	Canals	Percent accounted for by crop/ features	All crop/ features IR	All crop/ features NI
Black-bellied plover	19	42	37	-	+	+	-	-	-	-	79	+	+
Killdeer	287	11	+	10	+	+	+	+	4	+	25	+	68
Mountain plover	16	25	63	-	-	-	-	-	-	-	88	+	69
Black-necked stilt	28	25	+	+	11	-	7	11	-	-	54	+	+
American avocet	9	67	+	-	-	-	+	-	-	-	67	78	+
Greater yellowlegs	36	30	-	-	10	5	8	-	-	-	53	+	+
Lesser yellowlegs	6	50	+	+	-	-	-	-	-	-	50	+	+
Willet	18	39	+	-	-	-	+	+	+	+	39	+	+
Spotted sandpiper	29	+	-	-	-	-	-	-	-	-	83	100	-
Whimbrel	45	36	+	+	4	9	4	22	-	-	75	75	+
Long-billed curlew	53	11	27	13	+	+	8	19	+	-	78	+	68
Western sandpiper	10	40	+	-	-	-	-	-	-	+	40	70	+
Least sandpiper	61	30	+	+	+	-	+	+	18	+	48	64	+
Long-billed dowitcher	27	41	+	+	+	+	-	-	+	-	41	63	+
Common snipe	17	+	-	-	-	+	-	-	12	59	71	82	+
Wilson's phalarope	8	38	-	-	+	-	+	-	-	+	38	88	+
Ring-bill gull	37	30	46	+	+	+	+	+	-	-	76	+	65

characteristic of the willow-cottonwood association but have declined and continue to do so precipitously (Table 54) (Grinnell 1914; Hunter 1984). Other California species of special concern on the lower Colorado River not in immediate trouble include least bittern, sandhill crane (a wintering species only), brown-crested flycatcher, crissal thrasher, Lucy's warbler, yellow-breasted chat, northern cardinal (*Cardinalis cardinalis*), and Abert's towhee. The populations of these species are stable at present but should be monitored (Remsen 1978; Hunter 1984).

Arizona's list of threatened native wildlife includes great egret (*Casmerodius albus*), snowy egret (*Egretta thula*), black-crowned night-heron (*Nycticorax nycticorax*), common black-hawk, bald eagle, osprey (*Pandion haliaetus*), peregrine falcon, black rail, black-necked stilt (*Himantopus mexicanus*), yellow-billed cuckoo, willow flycatcher, and Sprague's pipit (*Anthus spragueii*) from the lower Colorado River. All of these species, except peregrine falcon and Sprague's pipit, are closely associated with emergent and riparian habitats. High priority reporting status is given to great egret, peregrine falcon, and black rail.

The number of listed species and those of concern in aquatic and riparian habitats attest to the dramatic changes experienced on the lower Colorado River. Birds have suffered more dramatic declines than any other faunal group, except fish. Almost all of these bird species would benefit from the increase of riparian habitat quality, especially increases in the amount of cottonwood-willow habitats.

Table 54. Estimated population changes in seven riparian bird species from 1976 to 1986 on the lower Colorado River. All these species were common to abundant at the turn of the twentieth century. Estimates are based on density data from 1976-1979 and total habitat size in 1976, 1984, and 1986 (see Chapter 6). Bird density data from Anderson and Ohmart (1984b). Scientific names in Appendix B.

	Population size			Percent change		Overall change
Species	1976	1984	1986	1976-1984	1984-1986	1976-1986
Yellow-billed cuckoo	450	353	261	-22	-26	-42
Gila woodpecker	883	690	561	-22	-19	-37
Gilded northern flicker	278	272	188	-2	-31	-32
Brown-crested flycatcher	806	714	437	-11	-39	-46
Bell's vireo	203	191	88	-6	-54	-57
Yellow-breasted chat	997	970	700	-3	-28	-30
Summer tanager	216	198	138	-8	-30	-36

Ironically, no Federally protected bird species represent these habitats. Preservation and restoration of cottonwood-willow habitats has not been of the highest priority, in practice, for Federal and State agencies, although wetlands are recognized on paper as in need of protection (Cowardin et al. 1979; Hunter et al. 1987).

CHAPTER 12. MAMMAL COMMUNITIES

Mammals are visually the least obvious of the vertebrate groups on the lower Colorado River. Mammals range from the most xeric to the most mesic habitats within the system (Table 55). Most species are at least partially nocturnal and are therefore difficult to study. Much of the existing data on habitat use, food habits, and behavior of mammals are based on trapping, collection of scats, and radio-telemetry techniques. These data are discussed in detail in addressing ecological, evolutionary, and conservation issues for much of the lower Colorado River mammalian fauna.

12.1 AQUATIC HABITAT USE

There are no totally aquatic mammalian species on the lower Colorado River. However, there are three species that are totally dependent and many species that are semidependent on aquatic habitats. One species totally dependent on aquatic habitats, the river otter (<u>Lutra canadensis</u>), has become very rare and possibly extirpated from the lower Colorado River.

Beaver (<u>Castor canadensis</u>) and muskrat (<u>Ondatra zibethicus</u>) occur in aquatic habitats, especially in quiet backwaters and in areas bordered by extensive stands of emergent vegetation. Beaver are most common in and around large stands of young willows; densities for this mammal are highest along the Bill Williams Delta and in Imperial National Wildlife Refuge where the best-quality habitat occurs. Muskrats are more widespread than beaver, occurring wherever emergent vegetation is present (even in canals). Both species are economically important for their fur. Beaver can cause extensive damage to small stands of regenerating willows and to cottonwood-willow revegetation efforts. Both the beaver and muskrat are primarily herbivorous.

Grinnell (1914) found much sign but few live muskrat and no beaver during his study. He speculated that the extensive trapping during the nineteenth century severely reduced both species. Muskrats have now become quite common in marshes and along extensive canal systems throughout the valley. Beaver have also recovered to some extent. Completion of major canals to Imperial Valley in 1911 allowed the spread of beavers into that area (Grinnell et al. 1937). Subsequent declines have occurred in the Imperial Valley population through continued trapping and periodic water shortages. Surveys on the mainstream lower Colorado River determined that there were 272 beavers in 1940 (Tappe 1942). Loss of riparian habitat to channelization, phreatophyte clearing, and concreting of canals has been extensive since that time and has been detrimental to beavers. Present population size is unknown and should be monitored (Williams 1986).

River otters occurred on the lower Colorado River at least until 1933 (Grinnell et al. 1937; Hoffmeister 1986). Apparently, they were never common and disappeared from the lower

Table 55. Mammal distribution and habitat use on the lower Colorado River. Distribution: N-S division = Parker Dam and the Bill Williams confluence; E-W division = the main channel of the lower Colorado River (Figure 1).

	Habitat					Distribution			
Species	Aquatic	Ripar.	Agric.	Desert	Resid.	NW	NE	SW	SE
Gray shrew (*Notiosorex crawfordi*)				X				X	X
California leaf-nosed bat[S] (*Macrotus californicus*)		X		X		X	X	X	X
Cave myotis[S] (*Myotis velifer*)		X		X		X	X	X	X
Arizona myotis[S] (*M. occultus*)		X						X	
California myotis (*M. californicus*)				X		X	X	X	X
Yuma myotis (*M. yumanensis*)	X	X	X		X	X	X	X	X
Western pipestrelle (*Pipistrellus hesperus*)	X	X	X	X	X	X	X	X	X
Big brown bat (*Eptesicus fuscus*)		X		X		X	X	X	X
Hoary bat (*Lasiurus cinereus*)		X						X	X
Southern yellow bat[S] (*L. aga*)					X				X
Townsend's big-eared bat[S] (*Plecotus townsendii*)			X	X		X			X
Pallid bat (*Antrozous pallidus*)			X	X		X	X	X	X

(Continued)

Table 55. (Continued)

Species	Habitat					Distribution			
	Aquatic	Ripar.	Agric.	Desert	Resid.	NW	NE	SW	SE
Pocketed free-tailed bat[S] (*Tadarida femorasacca*)			X						X
Raccoon (*Procyon lotor*)	X	X				X	X	X	X
Ringtail (*Bassaricus astutus*)			X				X		X
River otter*[S] (*Lutra canadensis*)	X	X				X	X	X	X
Badger (*Taxidea taxus*)		X	X	X		X	X	X	X
Western spotted skunk (*Spilogale gracilis*)			X	X		X	X	X	X
Striped skunk (*Mephitis mephitis*)	X	X	X			X	X	X	X
Coyote (*Canis latrans*)		X	X	X		X	X	X	X
Kit fox (*Vulpes macrotis*)				X		X	X	X	X
Gray fox (*Urocyon cinerargenteus*)		X		X		X	X	X	X
Mountain lion*[S] (puma) (*Felis concolor*)		X		X		X	X	X	X
Bobcat (*F. rufus*)	X	X	X	X		X	X	X	X
Round-tailed ground squirrel (*Spermophilus tereticaudus*)		X	X	X		X	X	X	X
Harris' antelope squirrel (*Ammospermophilus harrisii*)				X			X		X
White-tailed antelope squirrel (*A. leucurus*)				X		X		X	

(Continued)

Table 55. (Continued)

Mammal species	Aquatic	Ripar.	Agric.	Desert	Resid.	NW	NE	SW	SE
	Habitat					Distribution			
Botta's pocket gopher (*Thomomys bottae*)		X	X	X	X	X	X	X	X
Little pocket mouse (*Perognathus longimembris*)		X		X		X		X	X
Arizona pocket mouse (*P. amplus*)				X		X	X		
Desert pocket mouse (*P. penicillatus*)		X		X		X	X	X	X
Rock pocket mouse (*P. intermedius*)				X		X	X	X	X
Spiny pocket mouse (*P. spinatus*)				X		X	?	X	?
Long-tailed pocket mouse (*P. formosus*)				X		X		X	
Desert kangaroo rat (*Dipodomys deserti*)		X		X		X	X	X	X
Merriam's kangaroo rat (*D. merriami*)		X		X		X	X	X	X
Beaver[S] (*Castor canadensis*)	X	X				X	X	X	X
Western harvest mouse (*Reithrodontomys megalotis*)		X						X	X
Cactus mouse (*Peromyscus eremicus*)		X		X		X	X	X	X
Canyon mouse (*P. crinitus*)				X		X	X	X	X

(Continued)

Table 55. (Continued)

Species	Habitat					Distribution			
	Aquatic	Ripar.	Agric.	Desert	Resid.	NW	NE	SW	SE
Deer mouse (*P. maniculatus*)		X	X			X	X	X	X
Southern grasshopper mouse (*Onychomys torridus*)		X		X		X	X	X	X
Desert woodrat (*Neotoma lepida*)			X		X	X	X	X	
White-throated woodrat[S] (*N. albigula*)		X		X		X	X	X	X
Arizona cotton rat[S] (*Sigmodon arizonae*)	X	X						X	X
Hispid cotton rat (*S. hispidus*)	X	X						X	X
Muskrat (*Ondatra zibethicus*)	X	X				X	X	X	X
House mouse (*Mus musculus*)		X	X		X	X	X	X	X
Porcupine (*Erithion dorsatum*)		X		X					X
Black-tailed jackrabbit (*Lepus californicus*)		X	X	X		X	X	X	X
Desert cottontail (*Sylvilagus audubonii*)		X	X	X		X	X	X	X
Mule deer (*Odocoileus hemonius*)		X	X	X		X	X	X	X

(Continued)

Table 55. (Concluded)

Species	Habitat					Distribution			
	Aquatic	Ripar.	Agric.	Desert	Resid.	NW	NE	SW	SE
Pronghorn antelope* (*Antilocapra americana*)			X			X			
Bighorn sheep (*Ovis canadensis*)				X			X		X
Burro (*Equus asinus*)		X		X					
Horse (*E. caballus*)		X	X	X			X		X

* Extirpated (?).
S = State-listed, species of special concern.

Colorado River soon after the closure of Hoover Dam. The exact causes of declining populations of the river otter along the lower Colorado River are unknown, but riparian habitat deterioration and loss are undoubtedly involved. River otters are carnivores feeding on any small aquatic or semiaquatic vertebrate or aquatic macroinvertebrates. Almost all potential native prey species have been extirpated and replaced by introduced species. Perhaps loss of the native aquatic fauna also was involved in the disappearance of the river otter from the lower Colorado River fauna.

Aquatic and semiaquatic habitats are used extensively by otherwise terrestrial species. Many bat species, raccoon (*Procyon lotor*), striped skunk (*Mephitis mephitis*), coyote (*Canis latrans*), bobcat (*Felis rufus*), Arizona (*Sigmodon arizonae*) and hispid (*S. hispidus*) cotton rats, and mule deer are among the species most frequently found near water. Bats often forage for flying insects just above the water surface. Carnivorous species feed on macroinvertebrates (clams, crayfish), fish, frogs, semiaquatic birds (rails, marsh-nesting passerines), rodents (primarily both cotton rat species and muskrat), and carrion. Arizona and hispid cotton rats and mule deer forage along marsh edges on riparian and emergent vegetation.

12.2 RIPARIAN HABITAT USE

Most terrestrial mammalian species also can be found in riparian vegetation. The most xeric and open riparian habitats, such as stands of honey mesquite with shrubs, are dominated mostly by burrowing species. Frequently encountered species in xeric and open riparian habitats include badger (*Taxidea taxus*), coyote, kit fox (*Vulpes macrotis*), round-tailed ground squirrel (*Spermophilus tereticaudus*), desert pocket mouse

(Perognathus penicillatus), desert (Dipodomys deserti) and Merriam's (D. merriami) kangaroo rats, black-tailed jackrabbit (Lepus californicus), and desert cottontail (Sylvilagus audubonii). The round-tailed ground squirrel is the only strictly diurnal species, with all others being crepuscular or nocturnal. The ground squirrel, pocket mouse, and two species of kangaroo rat hibernate during at least part of the winter months. These rodents and the two lagomorphs are primarily granivorous or herbivorous, but take some animal matter (primarily insects). Carnivores are generalists, feeding on herbivorous mammals, small birds, reptiles, and large insects. Coyotes, the most general of the carnivores, eat vegetable matter, including honey mesquite seeds.

Riparian habitats closer to the river, with greater foliage density and diversity, harbor a different set of mammals. The most common species in cottonwood-willow, screwbean mesquite, dense honey mesquite, salt-cedar, and salt-cedar/honey mesquite mix habitats are raccoon, striped skunk, bobcat, deer (Peromyscus maniculatus) and cactus (P. eremicus) mice, and white-throated woodrat (Neotoma albigula). In addition, mule deer frequently occur in a broad range of riparian habitats. Other less common species include spotted skunk (Spilogale putoris), coyote, western harvest mouse (Reithrodontomys megalotis), southern grasshopper mouse (Onychomys torridus), and house mouse (Mus musculus). Desert cottontails are abundant along riparian edges with desert and agricultural habitats, but become less conspicuous in denser riparian vegetation. The southern grasshopper mouse is primarily insectivorous, while the other rodents are omnivorous. Carnivores feed primarily on small mammals, small birds, reptiles, and large insects. Bobcats are the most specialized carnivores, preying on small endotherms. Small and declining populations of mule deer feed primarily on willow, mesquite, and Atriplex spp., and are treated later in this chapter. Almost all mammalian species in riparian habitats feed, to one degree or another, on both screwbean and honey mesquite seed pods.

12.3 AGRICULTURAL HABITAT USE

Agricultural areas provide a tremendous food supply for granivorous and herbivorous mammalian species. Thus, the comparison of agricultural versus riparian habitat use is of interest to assess the importance of altered habitats to the native fauna. Vegetation adjacent to fields may have important influences on the number and species of mammals occurring in agriculture.

Weedy margins and adjacent riparian vegetation, for example, allow small rodent colonies to use agricultural crops by providing cover (Anderson and Ohmart 1982a). Rodent numbers are relatively low in areas where riparian edge is minimal and margins are cleared of weeds. In contrast, where fields are bordered by riparian vegetation and margins are weedy, species diversity and evenness are relatively high. The lack of cover, therefore, serves to decrease use. Predation by raptors, reptiles, and coyotes may serve to reduce rodent numbers in such open situations.

Botta's pocket gophers (Thomomys bottae) are abundant as subterranean feeders in agricultural areas but are less common in riparian vegetation in undisturbed areas. The deer mouse is the most common "riparian" rodent using agriculture. Other rodents occurring regularly in agricultural areas include desert pocket mouse, house mouse (near inhabited areas), and Arizona and hispid cotton rats (wet fields and marsh-bordered canals). Overall, field crops supporting the most rodents are cotton, milo, and wheat. Abundant weed and crop seeds and lack of extensive cultivation may make milo and wheat fields especially favorable for small rodents.

Desert cottontail rabbits are the most commonly observed mammal in agricultural areas and are also common in riparian habitats. Desert cottontail rabbits have similar reproductive success in both agricultural and riparian habitats as indicated by gonadal development (Anderson and Ohmart 1982a). However, overall reproductive success of female cottontails is greater in agricultural areas. Abundant and predictable food for cottontails may allow females in agricultural areas to reach reproductive conditions more quickly, invest more energy in young, and breed more frequently as compared to cottontails in riparian habitats. Differences in reproductive success between the two populations are greatest at the beginning and end of the breeding season, indicating the difference in available resources may be most important at these times. Greater reproductive success is balanced by greater mortality on adults and young in agricultural areas. Greater mortality is caused partly by predators responding to higher visibility of cottontails in agricultural areas. Overall, cottontails are heavier in body weight and are more common per unit area in agricultural areas, apparently in response to a predictable food source. The desert cottontail has different pressures exerted on agricultural populations (predation) compared with riparian populations (unpredictable food supply). Whereas cover is essential to most rodents in agricultural areas, it is not essential for maintaining healthy cottontail populations.

Large mammals rarely stray far from riparian habitats into agricultural areas. Mule deer feed in alfalfa fields but quickly escape to adjacent riparian vegetation at the first sign of danger. The only large mammal found regularly in agricultural areas is the coyote. Other large mammals observed in agricultural areas include beaver (canals), black-tailed jackrabbit, bobcat, feral horse (Equus caballus), burro (E. asinus), muskrat (canals), raccoon, round-tailed ground squirrel (margins and dirt canals), and striped skunk.

12.4 DESERT HABITAT USE

Desert habitats adjacent to the riparian zone harbor a number of unique species within the valley. Characteristic desert species are kit fox, rock squirrel (Spermophilus variegatus), Harris' (Ammospermophilus harrisii; Arizona side) and white-tailed antelope (A. leucurus; California side) squirrels and several pocket mouse species. Several mammal species are restricted, at least seasonally, largely to the desert mountains which border the valley. These species include gray fox (Urocyon cinereoargenteus), mountain lion (or puma; Felis concolor), mule deer, bighorn sheep (Ovis canadensis), and feral burro. Mule deer and feral burro are found regularly in the riparian zone, usually during the warmer months after forbs have passed their height of production in the desert uplands. Several mammals occur commonly in canyons bordering both desert and riparian habitats: coyote, desert cottontail, black-tailed jackrabbit, desert kangaroo rat, desert pocket mouse, and cactus mouse.

12.5 RODENT COMMUNITIES

Rodents constitute the largest taxonomic group of mammals in terrestrial habitats. Habitat use and interactions among rodent species are important topics of study in community ecology. Many rodent species, especially nocturnal ones, are easily trapped, and therefore habitat affinities can be delineated. Nocturnal small rodent communities were studied in all riparian plant communities and most agricultural field types on the lower Colorado River from 1974 to 1979 (Anderson et al. 1977; Anderson and Ohmart 1982a, 1984b). General habitat relationships for these species are described above. Below we describe in more detail the population biology, habitat selection patterns, and community ecology of primarily the riparian community and to a lesser extent agricultural and desert upland communities.

Riparian

Seasonal and annual fluctuations occur in rodent numbers of five common species (Anderson et al. 1977) (Figure 35). Seasonal fluctuations are most pronounced in heteromyid rodents (desert pocket mouse and Merriam's kangaroo rat), which hibernate during the winter. Desert pocket mice show the steepest drop in numbers during winter. Annual fluctuations generally were downward from 1974 to 1979 for all species and were most pronounced in cactus mouse, Merriam's kangaroo rat, and desert pocket mouse. There was also a trend for habitat breadth to increase as populations declined among cricetid rodents: white-throated woodrat, cactus mouse, and deer mouse. Conversely, desert pocket mouse and Merriam's kangaroo rat tended to decrease in habitat breadth along with steep declines in population size.

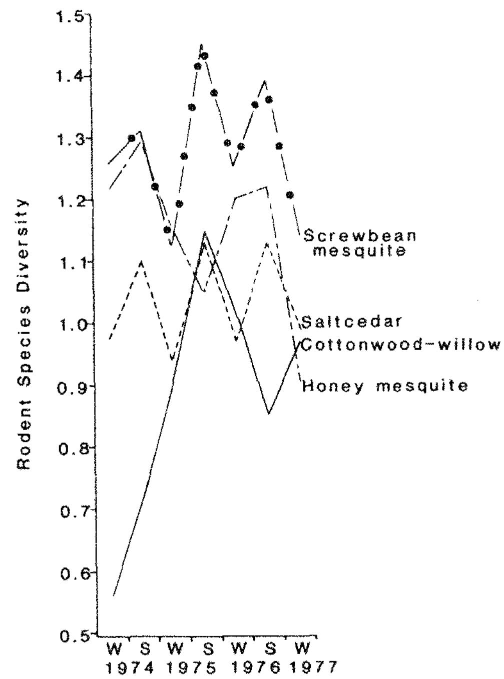

Figure 35. Rodent species diversities in four community types in the lower Colorado River Valley. Densities are calculated from the average densities (N/270 trap nights) of Peromyscus eremicus, P. maniculatus, Perognathus penicillatus, Dipodomys merriami, and Neotoma albigula caught in a given community type for a given time of year (Anderson et al. 1977).

These trends may be applied to two opposing ideas addressing habitat use proposed by Fretwell (1972). Species that increase in habitat breadth with increasing population size follow an ideal-free model, where reproductive success is equal even though densities may not be equal among habitats. Heteromyid rodents followed this pattern. The second model, the ideal-despotic model, applies to species, such as the cricetids, where habitat breadth decreases with increasing population size. In this scheme, reproductive success is not equal in all habitats, and therefore costs are incurred by individuals forced into less optimal habitats.

Reproductive activity of all rodent species is between March and August (Anderson and Ohmart 1984b; Table 56). Desert pocket mouse reproduction peaks later (May) than other species. Differences occur in litter size among species. Desert pocket mouse and deer mouse have larger litters (4.5 and 4.2 embryos, respectively) than do Merriam's kangaroo rat, cactus mouse, and white-throated woodrat (2.1, 3, and 2.3 embryos, respectively) (Anderson and Ohmart, unpubl. data).

Sex ratios also differ among the five most common rodents. Desert pocket mouse and deer mouse, both with high litter size, have a higher proportion of males in the population than species producing fewer young (Anderson and Ohmart 1984b) (Table 57). Desert pocket mouse and deer mouse also show greater average mobility than do species producing fewer young per litter. Higher natality, skewed sex ratios, and a greater movement may be indicative of a high juvenile-to-adult ratio and high dispersal or mortality. Excess juvenile or first-year males have often been recorded as dispersive and "floaters." Lower natality, an equal sex ratio, and greater site fidelity may be indicative of populations with few or no floaters, a high recruit-

Table 56. Percent of females pregnant for four rodent species during each month across five years (1974-1978). Sample size in parentheses. Vegetation and structure types combined. From Anderson and Ohmart (1984b).

	Percent of females pregnant			
Month	Cactus mouse	Deer mouse	Desert pocket mouse	Merriam kangaroo rat
January	4.8 (332)	4.5 (67)	0.0 (6)	2.8 (68)
February	15.8 (374)	25.0 (36)	6.3 (16)	24.2 (33)
March	4.0 (351)	56.0 (50)	0.0 (25)	45.1 (31)
April	51.0 (294)	43.3 (37)	7.5 (60)	46.0 (52)
May	45.0 (260)	31.8 (41)	33.7 (89)	69.5 (40)
June	44.3 (122)	43.4 (16)	27.6 (102)	45.5 (22)
July	42.2 (180)	43.1 (28)	45.7 (105)	25.9 (50)
August	26.0 (154)	67.0 (6)	17.7 (62)	28.9 (14)
September	10.2 (128)	17.5 (17)	4.0 (25)	0.0 (7)
October	9.5 (316)	14.3 (14)	0.0 (83)	0.0 (26)
November	5.0 (345)	5.8 (68)	0.0 (33)	0.0 (22)
December	63.0 (158)	6.7 (15)	0.0 (12)	0.0 (18)

Table 57. Percent of captured rodents that were female, by season, with years, vegetation, and structure types combined. Five years of data used (1974-1978). Sample size in parentheses. From Anderson and Ohmart (1984b).

Species	Season	
	Winter	Summer
Cactus mouse	46.0 (2799)	47.4 (2611)
Deer mouse	37.9 (499)	35.3 (439)
White-throated woodrat	56.2 (470)	50.2 (275)
Merriam kangaroo rat	44.3 (345)	43.6 (486)
Desert pocket mouse	35.3 (201)	38.3 (1030)

ment-to-dispersal ratio, and perhaps a less dispersive population.

The five most common rodent species were found in all riparian habitats surveyed and co-occurred regularly (Table 58). Similarities were observed in many characteristics among these species, including onset of breeding, peak of reproductive activity, and population response to seasonality and precipitation (Anderson and Ohmart 1984b). The desert pocket mouse was usually an exception. However, differences among species occur in litter size, distribution among habitats in relation to changes in population size, habitat association, sex ratio, and movement distances. These factors, mentioned above, influence habitat use and associations and, ultimately, influence rodent community dynamics.

The eight regularly trapped rodents basically fell into three distinct groups with regard to habitat associations (Figure 36). The cactus mouse, white-throated woodrat, and western harvest mouse reach greatest densities in areas with high foliage density and diversity. The cactus mouse reached peak abundance in saltcedar, the white-throated woodrat was most common in mesquite, and the western harvest mouse reached greatest numbers in stands with a large amount of vegetation above 4.6 m (15 ft) in height.

The second group includes desert pocket mouse, desert kangaroo rat, Merriam's kangaroo rat, and southern grasshopper mouse. These species were characterized by avoiding areas with dense vegetation. The desert pocket mouse and desert kangaroo rat were associated with fairly open stands of honey mesquite where shrubs were moderately abundant. Merriam's kangaroo rats were caught most often in moderately dense screwbean mesquite with reduced numbers in all other habitats. The southern grasshopper mouse occurred only within moderately dense vegetation and apparently had no plant species preference.

The third grouping consisted of the remaining species, the deer mouse. This species seems to avoid mesquite

Table 58. Number of rodents caught in summer and winter during the riparian vegetation study, 1974 to 1979, is expressed in the upper portion of the table. Number of trap nights in various habitats is expressed in the lower portion of the table. From Anderson and Ohmart (1984b).

	Number caught		
Species	Summer	Winter	Total
Cactus mouse	4128	4430	8558
Deer mouse	720	555	1275
White-throated woodrat	568	471	1039
Merriam kangaroo rat	873	533	1406
Desert pocket mouse	1573	209	1782
Southern grasshopper mouse			119
Western harvest mouse			70
House mouse			22
Hispid cotton rat			6
Desert kangaroo rat			65
Round-tailed ground squirrel			96
Harris' antelope squirrel			7
White-tailed antelope squirrel			7

	Structural type					
Vegetation type	I	II	III	IV	V	VI
Cottonwood-willow	7290	4320	7290	12,150	2970	10,530
Honey mesquite	----	----	7020	32,400	9990	10,800
Screwbean mesquite	----	4590	9450	20,790	13,770	2430
Saltcedar	3420	2970	5130	11,610	16,740	6750

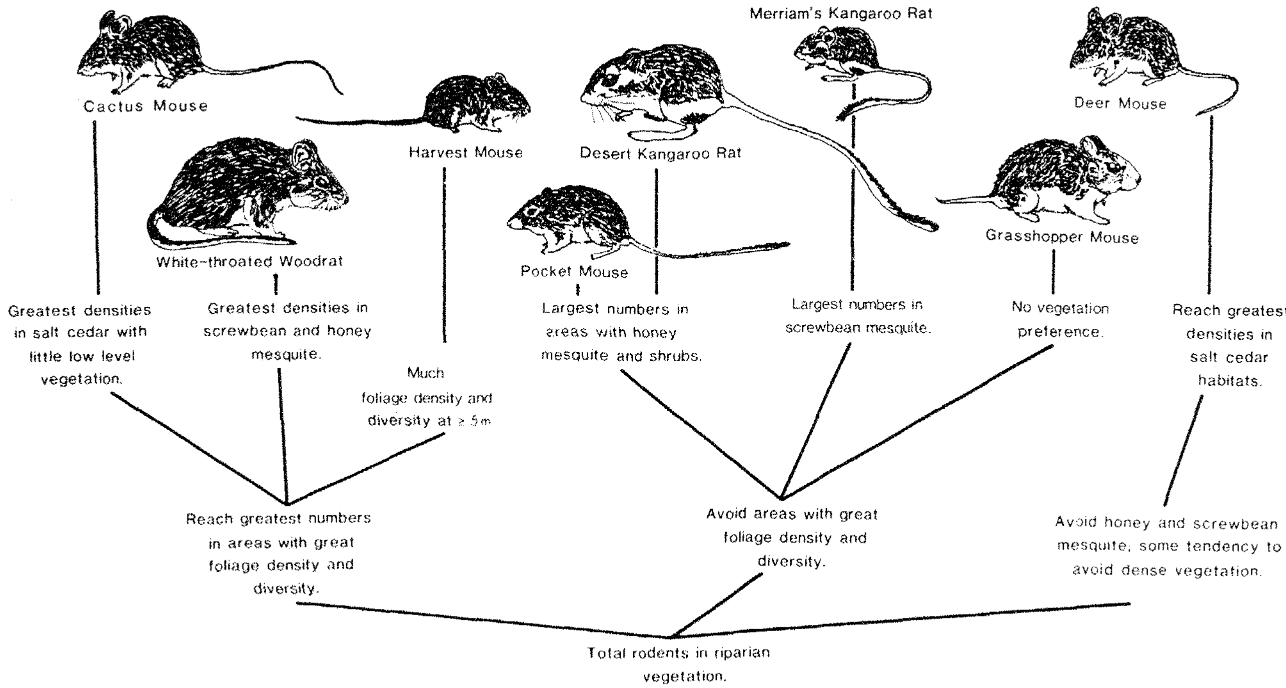

Figure 36. Summary of the vegetation relationships of eight species of rodents found in riparian vegetation along the lower Colorado River. From Anderson and Ohmart (1984b).

and, to some extent, very dense vegetation. The deer mouse was always numerically dominant in disturbed areas such as burns and clearings. It was also the most common riparian species using agricultural areas.

Other species were also captured (Anderson and Ohmart 1984b). Round-tailed ground squirrel was frequently captured in open habitats, primarily honey mesquite. Harris' antelope squirrel, a species typical of upland deserts, was found in small numbers in honey mesquite and saltcedar-honey mesquite plant associations. White-tailed antelope squirrel, also typical of upland deserts, was found only in saltcedar in the Parker Division. Cotton rats, both Arizona and hispid, were found most commonly in marshes but also in cottonwood-willow, screwbean mesquite, saltcedar, and saltcedar-honey mesquite plant associations in small numbers. Desert woodrats (<u>Neotoma lepida</u>) were occasionally found in cottonwood-willow habitats in the northern half of the valley. Finally, the house mouse was found in small numbers throughout the valley in cottonwood-willow, honey mesquite, saltcedar, and saltcedar-honey mesquite plant associations.

Among plant associations and structure types, no plant association appears to harbor more or less rodent species or individuals across structure types (Anderson and Ohmart 1984b). This trend was reflected by the five most common species frequently occurring together. Desert rodent communities are well known for their community structure being associated with relative sizes of the member species. Brown (1973:324), in his comparative desert rodent study, stated:

> One of the most striking characteristics of desert rodent communities is that component species differ greatly in body size...the more diverse communities consist of five or six species that show remarkable regular spacing in body size.

Brown's observations, however, do not hold for rodents of desert riparian systems as on the lower Colorado River. Of the five common species, three (deer mouse, cactus mouse, and desert pocket mouse) fall into the same size category. Spatial overlap measures show that these three species co-occur frequently among all riparian habitats (Anderson and Ohmart 1984b).

Brown (1973) also reported a low horizontal (spatial) foraging overlap between deer mouse and desert pocket mouse, two of the three similarly sized species. Anderson and Ohmart (1984b) reported a much higher overlap. There is relatively high spatial co-occurrence, with some separation by optimal habitat. Optimal habitats in summer or winter, however, tend to be different among the three species. Thus, there was at least some separation-based habitat preferences in some portion of the annual cycle.

Managing for maximum rodent species diversity in riparian habitats is no easy task. The wide overlap among species but different habitat preferences among species precludes any simple habitat-ranking scheme. The recommendation that is likely to benefit most species is to create an area that is horizontally diverse and possibly include saltcedar as a component species. The sandier the soil the more likely that heteromyid and sciurid species will be present.

Agriculture

Rodents were trapped in agricultural lands from July 1978 to August 1980 (Anderson and Ohmart 1982a). Deer mice accounted for more than 80% of all captures, thus any differences among crop types or agricultural areas were generally accounted for by differences in numbers of this species (Table 59). Other species regularly found were house mouse, desert pocket mouse, cactus mouse, hispid cotton rat, and Merriam's kangaroo rat. Western harvest mouse and southern grasshopper mouse were each captured only once.

Rodent species diversity values, averaged for all trapping periods, were very low for several reasons. Most important, some trap sessions caught only one species or no rodents, leading to a zero diversity value. Low numbers of rodent species and dominance by deer mice also contributed to low diversities.

Cotton and wheat fields consistently had high rodent species richness across agricultural areas (Table 60). Milo fields were relatively important in some agricultural areas. No single crop type had consistently low richness in all agricultural areas.

Agricultural areas apparently do not contain the essential elements for supporting a rich rodent community. Some opportunistic species such as the deer mouse will be present in most agricultural situations, but rich communities of rodents are unlikely to occur and, in general, they are not desired by farmers.

Diurnal rodents are represented in agriculture by one species, the

Table 59. Average number of rodents caught per 100 trap nights in each agricultural field type on the Colorado River Indian Reservation. Means with standard deviations in parentheses. -- indicates <0.1 or no captures. From Anderson and Ohmart (1982a).

	Field type							
Species	Plowed	Cotton	Milo	Alfalfa	Grass	Truck	Wheat	Total
Cactus mouse	--	0.1 (0.3)	--	-- (0.1)	--	--	0.1 (0.1)	0.2
Deer mouse	0.2 (0.4)	1.2 (1.3)	--	0.2 (0.4)	0.3 (0.5)	1.6 (2.6)	0.9 (1.0)	4.4
House mouse	--	0.1 (0.4)	--	0.3 (0.7)	0.3 (0.5)	0.1 (0.5)	0.1 (0.1)	0.9
Desert pocket mouse	-- (0.1)	0.2 (0.5)	0.5 (0.7)	0.1 (0.2)	--	0.1 (0.2)	-- (0.1)	0.9
Merriam kangaroo rat	--	--	--	-- (0.1)	--	--	--	--
Total	0.2	1.6	0.5	0.6	0.6	1.8	1.1	6.4
Total trap nights	3600	4400	200	4500	500	2800	1900	17,900

round-tailed ground squirrel. This species is common along field margins where they burrow. Burrowing owls often move into old ground squirrel burrows. Round-tailed ground squirrels also serve as food for diurnal raptors, except during midwinter hibernation.

Desert

No formal community studies of desert rodents on the lower Colorado River have been undertaken since Grinnell (1914), but numerous independent trapping efforts have been conducted (Hoffmeister 1986). Desert rodent communities are mostly made up of species found infrequently in the riparian zone. Five of six pocket mouse species are found only along the desert fringe of the lower Colorado River. The only other species found exclusively in desert uplands is the canyon mouse (*Peromyscus crinitus*). Species that primarily occur in desert uplands but also can be found in riparian habitats include Harris' and white-tailed antelope squirrels, desert kangaroo rat, cactus mouse, desert woodrat, and southern grasshopper mouse.

Basically, there are two major faunal associations in the desert habitats among rodents. Species found

Table 60. Average number of rodent species, total captures per 100 trap nights, species diversity (H'), and evenness (J) in each agricultural area. From Anderson and Ohmart (1982a).

Location	Field types										
	Citrus-dates	Grapes	Plowed	Cotton	Milo	Alfalfa	Grass	Corn	Wheat	Sugar beets	Truck
IMPERIAL-COACHELLA											
Number of species	3	4	3	5	2	3	3	1	3	4	-[a]
Mean total captures	2.1	1.7	4.7	9.0	6.6	2.4	3.2	17.0	4.7	7.4	-
H'	0.08	0.17	0.05	0.06	0.10	0.13	0.09	0.0	0.10	0.19	-
J	0.27	0.48	0.17	0.18	0.33	0.38	0.25	0.0	0.32	0.39	-
MOHAVE											
Number of species	-	-	3	5	4	-	-	-	4	-	-
Mean total captures	-	-	0.6	4.0	3.0	-	-	-	2.3	-	-
H'	-	-	0.05	0.15	0.09	-	-	-	0.18	-	-
J	-	-	0.11	0.40	0.22	-	-	-	0.33	-	-
COLORADO RIVER INDIAN RESERVATION											
Number of species	-	-	2	4	1	5	2	-	4	-	3
Mean total captures	-	-	0.3	1.6	0.5	0.6	0.5	-	1.1	0	1.8
H'	-	-	0.02	0.07	0.0	0.07	0.0	-	0.11	-	
0.02											
J	-	-	0.06	0.16	0.0	0.22	0.0	-	0.37	-	0.05

(Continued)

Table 60. (Concluded)

Location	Field types										
	Citrus-dates	Grapes	Plowed	Cotton	Milo	Alfalfa	Grass	Corn	Wheat	Sugar beets	Truck
CIBOLA NATIONAL WILDLIFE REFUGE											
Number of species	-	-	1	-	4	1	-	-	6	-	-
Mean total captures	-	-	1.0	-	3.1	1.6	-	-	2.2	-	-
H'	-	-	0.0	-	0.21	0.0	-	-	0.19	-	-
J	-	-	0.0	-	0.69	0.0	-	-	0.54	-	-

[a]Field type not trapped.

on level and sandy ground are round-tailed ground squirrel, desert kangaroo rat, Merriam's kangaroo rat, cactus mouse, desert pocket mouse, little pocket mouse (*Perognathus longimembris*; west side and east side south of the Bill Williams River), and Arizona pocket mouse (*P. amplus*; in the northeast portion of the valley). The second main species group occurs on rocky, rough terrain; however, some species differ on the two sides of the river. On the east side, rocky terrain is occupied by Harris' antelope squirrel and rock pocket mouse (*P. intermedius*), while on the west side white-tailed antelope squirrel, long-tailed pocket mouse (*P. formosus*), and spiny pocket mouse (*P. spinatus*) occur. Desert woodrat and canyon mouse occur in rocky areas on both sides of the river.

Geographic, habitat, and body-size distributions of the pocket mice along the desert fringe of the lower Colorado River reveal some interesting patterns. Among size classes, pocket mice species can be divided into small and medium sizes. The two small species are the little pocket mouse, which occurs on the California side and south of the Bill Williams River on the Arizona side, and the Arizona pocket mouse, which occurs only in the northeast portion of the valley. These two species are difficult to separate in the field, with the Arizona pocket mouse tending to be larger, but they are not sympatric within the valley (see Hoffmeister 1986 for details). Both small pocket mice are associated with open and level desert habitats with a heavy sand or gravel component in the surface soil (Stamp and Ohmart 1979; Hoffmeister 1986). Four species of medium-sized pocket mice can be found along the lower Colorado River, of which two are restricted to the west side of the river while one is restricted to the east side. The fourth medium-sized species is the desert pocket mouse, which is commonly found in sandy open desert on both sides of the river where vegetation is sparse; this species is also the only pocket mouse to use riparian habitats (Stamp and Ohmart 1979; Anderson and Ohmart 1982b). The spiny pocket mouse of the west side and the rock pocket mouse of the east side are ecological equivalents, with both being found in rocky slopes and canyons. The other west side, medium-sized species is the long-tailed pocket mouse, which occurs on narrow strips of loose sandy soil along desert washes separating elevated mesas; these habitats are not as flat and sandy as those occupied by the desert pocket mouse nor as sloped or rocky as those of the spiny pocket mouse (Grinnell 1914). It appears there is little or no geographical overlap among the six species of pocket mice with similar size or habitat preferences. In addition, there appears to be no habitat overlap among similarly sized sympatric species (Grinnell 1914); however, more in-depth studies are needed.

The existence of three similarly sized *Perognathus* on the west side of the river raises some interesting questions concerning distribution, ecology, and systematic relationships. The desert pocket mouse and the spiny pocket mouse are in the same subgenus (*Chaetodipus*) but do not overlap in habitat use. The long-tailed pocket mouse is similar in habitat use to the spiny pocket mouse, but has the center of its distribution north and west of the lower Colorado River. The spiny pocket mouse is most closely associated with boulders, whereas the long-tailed pocket mouse in desert wash habitats (Grinnell 1914). Grinnell (1914) commented that the long-tailed pocket mouse belonged to a separate subgenus (*Perognathus*) than did the spiny and desert pocket mice. He observed further that the species had different morphological structures and different diets than either of the other species.

Historic Rodent Communities

The major changes in rodent communities documented from the lower Colorado River since the closure of Hoover Dam in 1936 have occurred in the first bottom. Grinnell (1914) reported deer mice as one of the characteristic rodents in the willow-cottonwood association along with white-throated woodrat and western harvest mouse. The deer mouse is a successional species that invades heavily disturbed habitats. The frequently flooded first bottom was a classic example of a disturbed habitat. Western harvest mice apparently were well distributed and swam readily as they were often found on ephemeral islands within the mainstream. White-throated woodrats foraged extensively in the first bottom; however, their nests were located only at the interface of the first and second bottoms, dominated by honey mesquite.

Presently, with the stabilized river and infrequent flooding, the deer mouse has been replaced by the cactus mouse as the most abundant *Peromyscus* species. The cactus mouse during Grinnell's (1914) study was widespread but occurred infrequently within the first bottom. The cactus mouse currently is abundant in exotic saltcedar, screwbean mesquite, and cottonwood-willow, as well as in honey mesquite and desert uplands. In addition, Merriam's kangaroo rat and desert pocket mouse have become more widespread in the first bottom, where the surface soil remains dry. Where habitats are burned or cleared in the first bottom, the deer mouse tends to be proportionately more common, and it is the only rodent to occur commonly in agricultural habitats. Grinnell (1914) commented that the annual rush of floodwaters must have exerted a heavy toll on deer mice populations, but their high fecundity kept pace with mortality. Today, this invading species persists within habitats incurring longer-lasting disturbances caused by burning, clearing, and farming, while the cactus mouse has replaced it as the most common *Peromyscus* in the more stable riparian communities of the lower Colorado River.

Several species have noticeably changed in absolute abundance on the lower Colorado River. The western harvest mouse, one of the more common species in the riparian first bottom, was uncommon and infrequently captured in riparian habitats (Grinnell 1914; Anderson and Ohmart 1984b). Botta's pocket gopher has apparently increased within the confines of the valley with the advent of agriculture. Grinnell (1914) found only two locations with gopher sign, near Ehrenberg and at Pilot's Knob. The absence of gophers in the greater portion of the valley is explained by annual floods. Colonies of gophers invaded the river bottom only in habitats (salt bush or creosote bush flats) that occur back from the river. Beaver and muskrat have increased since Grinnell's (1914) study, when both species were heavily trapped for their furs. Finally, the two species of cotton rats (Arizona and hispid) apparently have increased in distribution, if not abundance, with the development of more emergent vegetation along the mainstream, in backwaters, and in canals.

The Colorado River and Patterns of Distribution

Patterns in morphological characteristics among populations of species and between closely related species occur in a north-south direction and on east-west sides of the river. These patterns are clearest among rodents associated with desert uplands. Generally, populations on the west side of the lower Colorado River remain similar from north to south. Patterns on the east side of the river are more complex, with some distinct differences between populations and species pairs north and south of the Bill Williams River (as in desert woodrat populations and between little and Arizona pocket mice; Hoffmeister 1986). On the west side, some species show a gradual paler pelage color (as in the round-tailed ground squirrel). There is also a tendency for populations on the east side to be paler farther south.

Species that live within the riparian zone show very few differences north to south and on either side of the river as they have free exchange throughout the system. Species that occur sparingly in the riparian zone are not well differentiated, as with desert woodrat in the northern part of the valley, little pocket mouse in the southern part of the valley, and desert kangaroo rat throughout the valley (Grinnell 1914; Hoffmeister 1986). Desert rodents, however, demonstrate notable differences between the two sides of the river and from north to south, especially on the east side. These species provide important examples of the interaction between geography and the distribution of populations and species.

There are three species pairs that are completely separated geographically. Species on the east side of the river (Harris' antelope squirrel, Arizona and rock pocket mouse) have centers of distribution well into the Sonoran Desert of central Arizona and reach the westernmost edge of their ranges at the lower Colorado River. Ecological equivalents (white-tailed antelope squirrel, little and spiny pocket mice) on the west side do not show similar centers of distribution as do species on the east side. The range of white-tailed antelope squirrel surrounds the range of its congener, the Harris' antelope squirrel, on the west, north, and east, although there is not at present a zone of overlap between the two. The Colorado River forms the barrier to overlap in the west (Hoffmeister 1986). Little pocket mouse has its center of distribution north and west of the lower Colorado River and apparently crossed the river often enough in the south to have spread east into central Arizona where it occurs sympatrically with the Arizona pocket mouse (Hoffmeister 1986). The spiny pocket mouse has its center of distribution in Baja California and extends into Nevada strictly on the west side of the river. There are some reports of spiny pocket mice on the east side near Martinez Lake and on the Bill Williams River; however, specimens have been either lost or confused with the morphologically and ecologically similar rock pocket mouse (Hoffmeister 1986). In addition, the long-tailed pocket mouse is also found only on the west side of the lower Colorado River, but does not have an ecological equivalent or a congener on the east side; the center of this species' distribution is north and west of the river. Overall, patterns of distribution indicate that many of these species dispersed toward the Colorado River, and the river served as a barrier to further dispersal east or west. It is also possible that the Colorado River served to separate previously contiguous populations, which eventually led to the divergent evolution of the present fauna (Hoffmeister 1986).

The most detailed study to date addressing the lower Colorado River as a genetic barrier in the systematics of a single species involves the Botta's pocket gopher (Smith and Patton 1980). Two subspecies converge, one from central Arizona and the other from southern California. This gopher is well known as being extremely divergent in phenotypic characteristics from one population to the next throughout its range; adjacent populations may differ as much as closely related species (Selander and Johnson 1973; Patton et al. 1979). On the lower Colorado River, the high level of interpopulation genic differences might suggest reproductive isolation. Alternatively, these differences also could be because of historical processes involving geographically determined restrictions to gene flow. These restrictions could include extrinsic, physical, or historical barriers to gene flow, not genetically based reproductive isolation (Smith and Patton 1980).

Grinnell and Hill (1936:9) noted that

> ...the effectiveness of the Colorado River as a barrier... increases northward from its mouth. Near its mouth, in the delta region, the river apparently is no permanent barrier at all, for the well-known reason that it is prone frequently to shift its channel....Farther up the river, despite similarities of climate, edaphic, and floral conditions on the two sides, we find greater and greater amounts of difference... between the separated populations of gophers.

Paired populations of pocket gophers along each side of the lower Colorado River become progressively more differentiated morphologically when proceeding north from its mouth to southern Nevada (Smith and Patton 1980).

Gopher populations from south to north are completely isolated because valleys are separated by the constrictions of desert cliffs such as those that divide Yuma from the Palo Verde Valley and the Palo Verde-Parker-Cibola Valleys from the Mohave Valley. Thus, gene flow is restricted from south to north on both sides of the river. Genetically, two major geographic groupings of populations are evident: (1) northern lower Colorado River with the Mohave Desert in California and (2) southern lower Colorado River with southern Arizona and southeastern California. Thus, morphologically based differences suggest east versus west populations, while genic variation suggest north versus south populations.

To explain the conflicting evidence, Smith and Patton (1980) proposed that genic characteristics are the most important in indicating population divergence, while ecological influences on phenotypic divergence are secondarily important among genetically closely aligned populations. They argue that external morphological characteristics of pocket gophers used in population studies (e.g., overall size, pelage color, cranial size, and proportional features) are under intensive selective pressures imposed by the local environment. They also argue that much morphological variation is probably phenotypic rather than genotypic in expression. For instance, pelage color often is tied to soil color, and upper incisor characters are associated with relative soil hardness. While the degree to which external influences result in particular phenotypes remains unknown, environmentally mediated ecotypic and ecophenotypic variation is a strong component of the morphological features that differentially characterize gopher populations. In contrast, the genic data reflect the long-term historical or genealogical relationships of populations, while the morphological data reflect the short-term historical processes that are more under the influence of local differential selective pressures. Thus, the degree of morphological difference between populations may be a poor indicator of both phylogenetic relationships of the populations in question and the length of time they have been separated. The opposite is true for genic data.

The evolution of pocket gopher populations in the lower Colorado River Valley can only be understood with thorough knowledge of the geologic history, land-use patterns, and life history of the gophers themselves. In desert regions, gophers are typically restricted to water courses and are rarely found in arid desert soils. River channels provide both initial access of gophers to desert regions such as those adjacent to the lower Colorado River and continued corridors for gene flow subsequent to colonization.

The main river drainages and associated topographic features in southern Arizona and southeastern California were developed before the end of the Tertiary Period (Kottlowski et al. 1965). The geographic pattern of genic divergence indicates that Botta's pocket gopher is divided into two major geographic units which currently meet at the Colorado River. The current spatial relationship between these two groups results from a secondary contact of previously isolated units, which probably occurred in the early to mid-Pleistocene (Patton and Yang 1977). Patton and Yang (1977) suggest that the extinction of other gopher genera led to the expansion of Botta's pocket gopher from both central Arizona and southeastern California to meet at the Colorado River. Fluctuating levels in the Salton Sink area probably allowed for westward movement and then eastward again, allowing colonization from west to east instead of south to north for pocket gophers up the lower Colorado River. This pattern may have continued as recently as 1905 with the filling of the present Salton Sea (Sykes 1937; Smith and Patton 1980).

The strong genic affinities of both west and east side populations above Yuma with populations in the Mohave Desert supports the view that the Palo Verde and Cibola-Parker Valleys on both sides of the river may have been colonized from the northwest at the same time. Strong genic affinities of gophers around Yuma with populations in central Arizona indicate a dispersal corridor along the Gila River. Populations then spread west into the Imperial Valley and then east again to valleys north of Yuma.

The development of agriculture has apparently allowed increased gopher populations throughout the valley. The control of flooding has also acted to stabilize many populations that otherwise would be impacted by high water. The combination of irrigated agriculture and control of river flow has also had dramatic effects on the geographic organization of gopher populations in the general region. Irrigation canals and roads provide gophers with connecting dispersal routes, even across the river. Botta's pocket gopher is also known to swim (Kennerly 1963). Finally, irrigated fields provide abundant year-round food supplies permitting the existence of dense, stable populations.

The lower Colorado River, both historically and today, presents a formidable barrier to dispersal for many terrestrial mammals, primarily rodents. Those species found within the first bottom riparian zone are often transported to opposite sides of the river and, therefore, maintain widespread gene flow. Upland desert species, though not directly dependent, are indeed affected by the lower Colorado River in determining limits of geographical distribution by maintaining isolation from closely related species through restriction of gene flow, and possibly in the divergence of new species where previously only one occurred. Patterns of distribution and relatedness among populations, however, can be very complex as shown with the Botta's pocket gopher, especially when a number of historical, geological, and ecological events come into play.

12.6 MULE DEER

Deer populations along the lower Colorado River are generally confined to areas where mountainous and rugged terrain is proximal to riparian habitats. Areas such as these are localized in both California and Arizona.

Historical information relative to deer numbers is virtually nonexistent, although there are scattered accounts by diarists of deer sightings. Since there have been few major habitat changes in the arid uplands adjacent to the river floodplain it seems reasonable to suggest that deer distribution patterns today are probably similar to what they were prior to European settlement. There is controversy on this point in that several references suggest that white-tailed deer (Odocoileus virginianus) occurred on the lower Colorado River into the early twentieth century (Burt and Grossenheider 1976; Rue 1978; Williams 1986). Hoffmeister (1986) states white-tailed deer never occurred as far west as the lower Colorado River. The specimen that is often referred to was actually a misidentified mule deer (Hoffmeister 1962).

Deer densities in riparian habitats, however, have probably changed dramatically over the past 100 years. European settlers may have caused declines in deer populations as they had more efficient hunting methods than Native Americans, they were not limited to seasons or limits on harvest, and they cleared riparian lands for farmland. After hunting laws were passed and enforced, concomitant with extensive acreages being planted into grain crops, there was an increase in deer populations. Water was proximal to escape cover that surrounded productive grain crops and frequently fields abutted dense riparian communities. This combination of factors enhanced deer populations and for a few years densities probably exceeded historical and current levels.

Continuing riparian habitat conversions with estimates of 1,200 ha (3,000 acres) lost per year (Anderson et al. 1978), combined with rapid and virtual extirpation of the cottonwood-willow community (Ohmart et al. 1977), has apparently directly affected deer populations either through cover limitations or forage availability or both. Concomitantly there has been a major shift from grain crops to cotton and truck crops. Only alfalfa remains as one of the favored food items for deer along the river.

Sparse but in-depth data on deer habitat use and timing of use of upland and riparian habitats exists. Information (Haywood et al. 1984) on four radio-collared does provides some insight into individual variations in deer behavior; the small sample and individual variation amplifies the caution of making broad generalizations. Weekly locations from May 1981 to June 1982 provided sample points where habitat utilization data were collected. Two deer resided near Lost Lake (Lost Lake does) on the California side 56 km (35 mi) north of Blythe. Another was in the Cibola National Wildlife Refuge (Cibola doe) in Arizona 61 km (38 mi) south of Blythe, and the fourth was near Walter's Camp, CA (Vinagre Wash doe) 70 km (43 mi) south of Blythe.

In general, does depended heavily on riparian habitats from late May-early June to late September-early October. Does living in arid upland habitats appear to move into lush, shaded riparian habitats as summer temperatures rise and uplands become hot and dry. The Vinagre Wash doe intermittently returned to the riparian habitats in fall, winter, and spring, but the Cibola doe resided in riparian habitats year-round, with occasional trips into the desert upland.

The Cibola doe occurred in areas with significantly less understory, shorter trees, and less foliage than the other deer. The Vinagre Wash doe used the densest riparian habitats at the 1.5 to 3.0 m (5 to 10 ft) level. One of the Lost Lake does used very little saltcedar habitat, whereas the other three used saltcedar. The Cibola doe used honey mesquite-dominated habitats significantly more than the others. The other three does also used screwbean mesquite habitat significantly more than the Cibola doe. Distance from agriculture was significantly greatest by the Vinagre Wash doe, and distance to water was significantly greatest by the Cibola doe. Many of these differences are apparent as each radioed doe is discussed relative to the habitats they used.

Cibola Doe

The low value for foliage density of ground-level vegetation (0.15-0.6 m [0.5-2 ft]) for the Cibola doe was because the majority of the deer location points were in dense, mature stands of honey mesquite trees bordering agricultural fields. The total foliage density was lower than that of the control. Both of these occurrences are unique among the three deer compared with their controls. The Cibola doe used honey mesquite trees to a much greater extent than did the other three does. There was no evidence of foraging on honey mesquite pods, although heavy browsing was observed on a few selected young trees in open habitat. Honey mesquite pods have a tough exocarp, and the seeds may be large enough to make digestion difficult. Seeds were as large or larger than most of the deer pellets observed. Pellet groups observed in the honey mesquite border around the Cibola agricultural fields were from deer feeding in alfalfa fields and then moving into adjacent stands of honey mesquite for shade and escape cover.

Seasonal data showed a higher use of screwbean mesquite and willow trees during the fawning season and in fall. The Cibola doe apparently selected a site near a permanent water supply. Fawns were produced along the river on the first terrace (Ohmart and Anderson 1982) in stands of screwbean mesquite and willow trees. During this time the doe was in dense vegetation, especially at the 1.5-3.0 m (5 to 10 ft) layer, which offered the greatest amount of shade during the hottest season. Screwbean mesquite and willow trees were nearby and, therefore, the doe did not have to travel far from the newborn fawn to obtain water and food. As the fawn matured, the doe and fawn moved away from the river toward the agricultural fields. During late fall and winter alfalfa fields were probably important to the doe. Available alfalfa could be part of the reason the Cibola doe remained in the riparian habitat in October. The expanse of riparian vegetation was great in this area, whereas the Lost Lake "A" and "B" does and the Vinagre

Wash doe inhabited relatively narrow strips of riparian habitat.

Vertical and horizontal foliage diversity of the Cibola doe habitat were significantly lower than for habitats of the other three deer. This doe preferred a more open habitat, with not particularly tall vegetation and with little understory.

The seasonal foliage height diversity data indicate that during fawning the Cibola doe moved into vegetation less vertically diverse than it occupied in summer. The willows and screwbean mesquite were not tall, mature trees. This may be an important consideration, since areas with tall, mature trees may not have as much forage available to deer; the bulk of the food resource might be out of reach.

During fawning, the Cibola doe moved into areas with significantly more saltcedar than was present in summer location points. The need for greater thermal cover during the hottest period of the summer would account for deer occupying areas with more saltcedar. Dense stands of mature saltcedar have little low-level vegetation, thus permitting increased ventilation and litter accumulation is generally very high. Litter traps soil moisture and, if ventilation is good, temperatures in these areas may be relatively mild and thus more favorable to a pregnant doe or newborn fawn.

Because honey mesquite trees were abundant immediately adjacent to alfalfa fields, the large number of honey mesquite trees present in location points during the summer season may indicate that the Cibola doe was feeding in the alfalfa fields and then bedding in surrounding honey mesquite agricultural-riparian edge. Honey mesquite and willow trees were found significantly more often in deer bedding sites than were other tree species. The Cibola doe had more bedding sites in honey mesquite than the other three deer, whereas the other three does seemed to prefer to bed in areas with numerous willow trees.

Distance of deer from the river may be misleading during summer. At this time deer were found near irrigated agricultural fields. Thus water from flooded fields and canals was continually available. In summer, high use of bordering honey mesquite for thermal cover was observed.

<u>Lost Lake "A" and "B" Does</u>

The Lost Lake "A" and "B" does were found in basically the same area; however, they appeared to use the riparian vegetation differently. Foliage height profiles were similar for both deer, but tree species used were different. Both deer were found in screwbean mesquite-willow communities near the river (unchannelized and not rip-rapped).

Both of these deer used denser parts of the habitat. The major difference in habitat use between these two deer was in their use of willow. The Lost Lake "A" doe used significantly less willow than was found in controls. The Lost Lake "B" doe used willow to a significantly greater extent than did the Vinagre Wash and Cibola does. The Lost Lake "B" doe used willow four times as often as the Lost Lake "A" doe. The Lost Lake "B" doe was found in saltcedar significantly less often than any of the other does. Screwbean mesquite was favored by the Lost Lake "B" doe. The Lost Lake "A" doe used alfalfa in its diet, whereas the Lost Lake "B" doe was never located in or near alfalfa fields. The Lost Lake "A" doe stayed closer to the river than did the Lost

Lake "B" doe. The high foliage height diversity of Lost Lake "B" doe location points reflects the use of tall willows and screwbean mesquite stands extending into arrowweed. Thus in Lost Lake "B" doe location points, vegetation was present at all height levels, resulting in high foliage height diversity.

Vinagre Wash Doe

This doe also inhabited the first terrace vegetation near the river. Foliage density at 1.5-3.0 m (5 to 10 ft) was significantly greater than that of the Lost Lake "A" and "B" doe sites, and this contributed to a significantly greater total foliage density than that of the Lost Lake "A" and Cibola deer sites. The Vinagre Wash doe occupied the densest area and was observed in areas farthest from agricultural fields.

The first terrace had the highest deer use. Many pellet groups (up to 12 groups) were found in a 929-m^2 (10,000-ft^2) plot in dense screwbean mesquite. Screwbean mesquite seeds were frequently observed in pellets. The habitat consisted of stands of screwbean mesquite and willow bordered on both sides by saltcedar and arrowweed. Various trails were observed leading to watering sites with abundant cover. The Vinagre Wash doe had a stable food supply, plenty of thermal cover, and easy access (152 m [500 ft]) to water sites.

The Vinagre Wash doe traveled from an area north of Walter's Camp to an area south of Walter's Camp before moving out of riparian vegetation to desert uplands. The Lost Lake "A" doe moved back and forth along the river in a north-south direction. The Lost Lake "B" and Cibola does tended to move in an east-west direction in the riparian habitat. Possibly after an area was used for a period, the does moved to another area to feed, bed, and water.

Nutritional Considerations

Deer select the most nutritious forage available (Klein 1962; Swift 1948). Urness and McCulloch (1973) studied the change of six nutrient factors (protein, phosphorus, calcium, acid detergent fiber, *in vitro* digestibility, and phosphorus-calcium ratio) in white-tailed and mule deer forage throughout the year in Arizona chaparral habitat. Their analysis indicated that in early spring nutrition is at a high point for deer. Winter rains stimulate spring forb production in desert uplands and washes, providing exceptionally high-quality forage. Urness et al. (1971:474) stated that, "...the importance of herbaceous forages in supplying phosphorus and protein cannot be overstated." During early spring, calcium is at desired levels, acid detergent is low, digestibility is high, and the phosphorus-calcium ratio is between 2:1 and 1:2. According to Dietz et al. (1962), a phosphorus-calcium ratio smaller than 1:5 leads to an inhibitory effect that calcium has on the ability of deer to utilize phosphorus.

In desert washes and adjacent uplands along the lower Colorado River, herbaceous forage becomes available following late summer and winter rains. After these rains the Cibola and Vinagre Wash does may make short trips away from the riparian habitat. Browse species such as willows in riparian habitat are not at an active growth stage in fall and early winter, and possibly levels of phosphorus and protein are inadequate (Urness and McCulloch 1973). Deer will take green herbaceous material whenever it becomes available to fulfill phosphorus needs (Swank 1958). The Lost Lake "A" and "B" does inhabited desert uplands in fall, winter, and spring. By covering the topographical extremes (i.e., slope, altitude, and exposure) of the desert ranges, the deer were essentially prolonging the growing season of high-quality forage. In the Arizona chaparral, spring forbs mature in late May and the nutritional quality of these herbaceous plants decreased; thus, the deer included more browse in their diet (Urness and McCulloch 1973).

Woody fruits of leguminous shrubs have been recognized as a valuable source of protein and phosphorus for mule deer (McCulloch 1963, 1967). Along the Colorado River, screwbean mesquite pods drop from the trees year-round but peak in early July (Ohmart and Anderson 1982). Numerous deer pellet groups (as high as 12 groups in a 929-m^2 [10,000-ft^2] plot) were found in stands of screwbean mesquite. The pellets contained many screwbean mesquite seeds, indicating that they were important forage. In central Arizona, woody fruits from leguminous shrubs composed nearly two-thirds of mule deer diet (Urness and McCulloch 1973).

Willow leaves were often eaten by deer in riparian habitat. Willows begin leafing out in February and drop their leaves in December. Deer especially eat new shoots from the trunk as well as leaves and twigs. Willow, screwbean mesquite, and arrowweed are found in close proximity to one another on the first terrace along primary riparian drainages (Ohmart and Anderson 1982). Dietz (1965) reported that in many Western summer ranges, willow provided the best source of protein for deer. Thus, deer foraging on screwbean mesquite pods and browsing on willows would have a high intake of protein and phosphorus all in close proximity to a reliable water source, an important factor during summer months.

The Lost Lake "A" and "B," Cibola, and Vinagre Wash deer returned to riparian habitat in June when highly nutritious forage was available and possibly high in phosphorus. Phosphorus is important in the formation of adenosine triphosphate, which is a source of high-energy phosphate bonds. Energy and protein are necessary for production of fawns, lactation, and antler development. A deficiency of phosphorus affects deer in the following ways: (1) retards growth, (2) depresses appetite, (3) greatly reduces milk production, (4) causes irregularity in ovulation, and (5) results in improper cleaning by females when giving birth to young (Swank 1958). Stanley (1951 In Swank 1958) remarked that phosphorus was the element most likely to be deficient in native Arizona range plants.

During fall and winter the phosphorus-calcium ratios widened to 1:10 in central Arizona (Urness and McCulloch 1973). Calcium levels increased greatly, whereas phosphorus levels decreased in deer forage species. The low level of phosphorus in riparian vegetation along the Colorado River could cause mule deer to leave riparian habitat in search of green browse in adjacent desert washes. Consumption of ironwood, which grows in desert washes, may help narrow the phosphorus-calcium ratio. This possibly would explain the sudden movement of Lost Lake "A" and "B" does into the desert foothills in early October. The Cibola doe had an abundant supply of herbaceous forage in nearby alfalfa fields. Therefore, widening phosphorus-calcium ratios probably are countered by an increase in alfalfa intake. Alfalfa is an extremely nutritious and easily digested forage. It is high in protein and phosphorus and low in acid detergent fiber (Bolton 1962). The Vinagre Wash doe traveled along the stands of screwbean mesquite and willow and then traveled south 3.2 km (2 mi), using this riparian area for three months (December-February), possibly finding isolated pockets of screwbean mesquite pods and willows that were still available as forage. However, the doe did move into desert washes for short intervals, perhaps in response to winter rains and availability of forbs and ironwood browse.

In general, deer along the lower Colorado River used screwbean mesquite and willow stands in the first terrace where they were available, except along areas where the riverbanks had been riprapped. The woody fruits of screwbean mesquite may be an important source of protein for pregnant does in August and September. Presence of riprap may prevent or limit deer access to water.

Deer need cover to move from mountainous terrain to the riparian vegetation in the first terrace, but extensive removal of honey mesquite along the second terrace may eventually eliminate most of the travel cover. If so, deer populations may eventually disappear along the river.

We have observed consistent deer use of one of our experimental revegetation plots during summer. In this plot, we have planted cottonwood, willow, honey mesquite, and blue palo verde trees in ratio of 5:4:2:1. When first used by deer, the area was three-years old, with trees up to 10 m (33 ft) tall. Foliage diversity was high, and density of trees was moderate. Bermuda grass and quail bush (high in protein content) were moderately abundant. Alfalfa is immediately adjacent to the area, and the river is within 100 m (328 ft). The river has been straightened and the bank has been rip-rapped, but the deer could be obtaining water from irrigated fields and unrip-rapped drainage canals.

12.7 BIGHORN SHEEP

Historically, this species was found in all mountain ranges adjacent to the Colorado River. Population levels have suffered from a number of causes, but reasons most frequently given are overgrazing by domestic livestock, diseases of domestic livestock, competition with feral burros, market hunting, poaching, and lack of river access. Each mountain range has been subjected to at least one or a concert of these activities. Though not all sheep populations have been extirpated, some have been or are precariously close. Further, sheep are intrinsically sedentary, especially ewes and lambs, consequently they are considered poor pioneering species. This behavior and the above decimating factors may have led to the extirpation or near extirpation of sheep in mountain ranges adjacent to the Colorado River and throughout the Southwest. Recent conservation efforts by State, Federal, and private groups have begun to reverse downward trends in selected mountain ranges. Management must include such efforts as reducing or eliminating grazing of domestic livestock, elimination of domestic sheep use in mountain ranges, and reintroducing new herds or adding sheep from other ranges to declining or relict populations.

The Colorado River and its riparian resources may not be vital to the sheep populations under discussion, but the animals frequent the river in the summer months for water. Riparian communities may also provide verdant forage and shade during these months. Limited study has demonstrated that sheep populations use riparian resources during the hotter and drier summer months (Seegmiller and Ohmart 1981).

Desert bighorn sheep are not on the Federal threatened and endangered species list, but do occur on State lists in Nevada, Arizona, and California. In Arizona, they are classified as a Group 3 species, which is defined as "Species or subspecies whose continued presence in Arizona could be in jeopardy in the foreseeable future. Serious threats to the occupied habitats have been identified and populations (a) have declined or (b) are limited to few individuals in few locations" (Arizona Game and Fish Commission, 1982:12). In California, all subspecies are recognized as fully protected by legislation, with the California and cremnobates races as threatened (Wehausen et al. 1987). This means that if habitat losses continue these races face extirpation. Two populations of the race nelsoni are allowed to be hunted. The populations occur in the Marble Mountains and on Old Dad Peak.

Arizona has had a very conservative hunting program for a number of years and this has generated both interest and funds to better manage sheep populations. It has also stimulated hunter organizations to actively procure funds for the development of more permanent waters and to fund reintroduction efforts. Two hunting permits have been set aside annually, one to be raffled and one auctioned. These efforts have produced in excess of $130,000 each year for improved sheep management activities.

Recently, California initiated a similar program, and the first legal sheep hunting permit was auctioned in 1987 for $70,000, and the 1988 permit earned $59,000. Not only will the funds generated by the permit help in supporting better sheep management, but also, as in Arizona, it will generate more public interest in the species and provide incentive for better management.

Bighorn Sheep Population Level

This section provides a general assessment of population numbers and general population trends of desert bighorn sheep in mountain ranges proximal or adjacent to the river. Mountain ranges a few miles from the river and areas along the river that the sheep are probably not using as a water source or forage base were not included. Mountain ranges considered begin at Davis Dam at the north and terminate at the International Boundary with Mexico.

Arizona. Needles Peak north of Lake Havasu City has an estimated population of 15-30 sheep and the trend is down. A transplant is proposed in this range in 1988. Aubrey Hills currently supports 30-45 head; the trend is down and a transplant is proposed in 1988. The Bill Williams Mountains currently have an estimated 40-50 head following a transplant of 22 head in 1986. The Buckskin Mountains contain 30-45 head after 8 sheep were introduced in 1985 and 14 more released in 1986. The Dome Rock Mountains currently contain 45-65 sheep, and the population is stable. Laguna Hills near Cibola National Wildlife Refuge has primarily a transient population ranging from 0-5 sheep. All data were supplied by Mr. Raymond Lee, Big Game Supervisor, Arizona Department of Game and Fish, Phoenix.

California. Estimates in the Chemehuevi Mountains are 20 sheep or less and the population is stable or declining. Sheep were extirpated from the Whipple Mountains, but have recently been reintroduced and numbers now are estimated at 100 animals and increasing. Sheep have been extirpated from the Big Maria Mountains but reintroduction efforts are being planned. The Jullian Wash area (east Chocolate Mountains) contains about 100 sheep and the population is stable or increasing. The above data are from Mr. Vern Bleich, California Department of Fish and Game.

General Biology

This section is drawn primarily from data published by Seegmiller and Ohmart (1981) for the Bill Williams Mountains and Aubrey Hills area south of Lake Havasu City. About 17 ewes, yearlings, and lambs inhabited the area, and the population was considered remnant or essentially gone by the Arizona Department of Game and Fish. Annual recruitment was low during the study period and, subsequently, additional sheep were introduced to the area.

Generally, bighorns extended their movements farther from the river during cooler months (November-April) and had reduced home ranges in warmer months (May-October). They primarily used foothill habitats in warmer months and long steep slopes in winter and early spring. The mean distance from the river or permanent water in summer months was 0.5 to 1.0 km (0.3 to 0.6 mi). They watered at all hours of the day and individuals as frequently as every other day.

Diet consisted of 8% grasses, 31% forbs, 54% browse, and 7% unknown. Bighorn sheep used 58 plant species, with the annual forb Indian wheat (Plantago insularis) being preferred (16% of the diet). The next most important species (based on percent of diet) were globe mallow (Sphaeralcea spp.; 8%), desert lavender (Hyptis emoryi; 8%), Bermuda grass (7%), little-leaf palo verde (Cercidium microphyllum; 7%), forget-me-not (Cryptantha spp.; 6%), and burro-bush (Ambrosia dumosa; 5%). These 10 species made up 67% of the annual diet of sheep. Bermuda grass was the only graminoid species appearing at any significant level, and it was primarily taken in the floodplain during hot, dry months. Sheep also watered from the river during this period.

Breeding activities began in early July, and by early August the four rams had joined the ewes and yearlings. Rams remained with the herd until April. Lambs were born during January and February.

Bighorn Sheep-Burro Interactions

Burros occupied a large proportion of bighorn range during June through October (65%), November through March (100%), and April through June (85%). Burros used foothill habitat during all seasons, while bighorns primarily used these habitats in the warmer months. In areas of sympatry, greatest overlap in habitat use occurred during November through March and April through June on long steep slopes and foothills, respectively.

Burros used 49 plant species, which included 64% of the 58 plant species eaten by bighorns. The annual forb Indian wheat was preferred by burros (26%) and bighorn sheep (16%). Vegetation proximal to the river showed definite signs of heavy use by burros. Palo verde trees were frequently devastated by burros, with all limbs being broken from the main trunk and left lying dead around the 2 to 3-ft (0.6 to 1 m) high trunk.

Interspecific conflicts at watering sites in the summer and at bighorn lambing grounds were not observed. The two species were frequently observed in close proximity in both spring (after lambing) and summer, but neither species appeared to pay particular attention to the other.

The high degree of overlap in both diet and habitat utilization in the above study did not demonstrate burro-bighorn competition in the strictest sense, but Seegmiller and Ohmart (1981) concluded from both empirical data and competition theory that the two species were limited by the fraction of the total vegetative biomass of sufficient nutritive value and digestibility for growth and reproduction. The larger burro population size, more rapid rate of increase, and cecal digestion indicates that this species would be a superior competitor over bighorn sheep. They concluded:

> ... desert bighorn are too valuable a natural resource and too limited in numbers and distribution to accept the risks of coexistence with burros. We recommend the removal of burros from areas where they are sympatric with desert bighorn sheep and from areas that have the potential for future bighorn sheep transplants (Seegmiller and Ohmart 1981:54).

12.8 FERAL BURROS

This species was introduced into the New World in the sixteenth century by the Spanish. Although some may have escaped from their owners during this time, free-roaming feral burros did not become a significant part of the desert Southwest until late in the nineteenth century. Widespread feralization occurred during the decline of mining activities and improvement of the road and rail systems (McKnight 1958).

Domestic livestock must have begun spreading north and westward to the Gila and Colorado Rivers by the early 1700's (Forbes 1965). Father Kino crossed the Colorado River near Yuma in October 1700 (Martin 1954), and his party was well stocked with horses and mules so that he could leave some for relays (Bolton 1932). Mule raising was one of the functions of the two Arizona missions, Guevavi and San Xavier del Bac, established by Kino. Though they apparently contained only a few animals, they were to supply mount and pack animals for Kino's expeditions. The Guevavi Mission contained a small herd of mule-breeding mares and a burro when transferred to Pfefferkorn in 1737. The visita at Sonoita contained a "...new herd of 13 males with its little burro," while San Xavier possessed 100 mares, 4 stallions, and 2 jacks in 1765 (Kessell 1970).

Horses were a common trade item to the Colorado River tribes by the mid-1700's. When Anza crossed the Colorado River in 1774 as he blazed a trail from New Spain's capital at Arispe to the California missions, the Quechan tribes had "an abundance of horses and mules" (Forbes 1965). Mules and burros were apparently still rare, as the Indians had great fun trying to imitate these animals (Forbes 1965).

The two missions established by Father Garces to protect the strategic Yuma Crossing along the Anza trail were short-lived. They lasted only a few years and were destroyed by the Indians in 1781 (Mattison 1948). This effectively closed the California trail to non-Indians for almost 45 years, since there were no Spanish settlements north of Yuma on the Colorado River.

This isolation ended in 1849 when gold was discovered in California. Some 6,000 to 9,000 Anglos and 6,000 to 15,000 Mexicans passed over the Yuma route in that one year (Forbes 1965). Indians helped the gold-crazed prospectors swim their reluctant horses across the swift river crossing. Unfortunate animals that did not survive the crossing efforts were quickly dismembered by the Indians. William A. Chamberlain had a mule drown as he crossed the river in 1849 and he wrote:

> The Indians brought it on shore and in a short time every part of it was carried away. The first butcher cut out the entrails and lugged them off, as the most delicate part and the last took the head...and trudged away, well satisfied with his share (Chamberlain 1945).

Despite the number of horses, mules, and burros that funneled into the Colorado River environs during this period, it is highly doubtful that any became residents because of their value for food and work. Burros were introduced to the hills and mountains along the river beginning in 1858, when gold placers were discovered in Gila City. Four years later, Captain Weaver discovered gold in an arroyo northeast of the soon-to-be town of La Paz. The big gold rush was on, and La Paz supported 1,500 miners within a few months of its founding (Browne 1887).

Ore was loaded into baskets or socks on the backs of these hardy and sure-footed animals to be carried out of the dry, hot hills to stamp mills on the river. On the return trip they carried water, supplies, and machinery. The mining boom essentially ended in 1880, but larger mines were active to as late as the 1930's. With mining virtually over and the railroads in place in the late 1800's, burros were excess baggage. The worthless pack animals were freed to wander and support themselves. At least 38 mines existed along the river and mountains in California and 49 in Arizona from Davis Dam south to the International Boundary (Sherman and Sherman 1969; Love 1974). The widespread release of this exotic, preadapted to desert environments, produced flourishing populations in mountain ranges all along the river.

The burro, native from the severe deserts of northeastern Africa, was well-adapted prior to its introduction into North American deserts. As a large successful herbivore it was in conflict with ranching interests and was considered a threat to native species, especially the desert bighorn sheep. Large numbers of burros were shot annually by ranchers, hunters, and wildlife personnel. Numerous others were captured and sold as pack animals, pets, or for pet food (McKnight 1958). Although these reductions kept densities at low levels and, possibly, distributions reduced, their feral existence was not threatened.

California passed a burro protection law in 1953 and a Federal law protecting free-roaming burros on public lands was passed in 1971. Both laws emanated from an emotional and poorly informed public and a lack of concern among ranchers and biologists. These laws have curtailed abusive and inhumane treatment of burros, but with the absence of predators, management, and control many populations are increasing to the degree that some desert ranges that support these "living monuments to the West's colorful past" are threatened.

Though much remains to be learned about the burro, intensive studies in the Chemehuevi Mountains in California (Woodward and Ohmart 1976) and the Bill Williams Mountains in Arizona (Seegmiller and Ohmart 1981) provide a good understanding of their general ecology. The Arizona study area also contained a desert bighorn sheep population and the potential for interspecific competition was discussed in the Desert Bighorn Sheep section.

Chemehuevi Mountains, California

These mountains abut the river near Blankenship Bend at the north end of Lake Havasu. In winter and after rains this burro population disperses up to 10 to 13 km (6 to 8 mi) inland from the river. In summer months individuals and herds seldom venture more than 3 km (2 mi) inland. During these hot, dry months individuals usually watered every 24-hour period, generally drinking in early morning or late afternoon (Woodward 1976).

Burros preferred desert bajada habitat whenever cured annuals were available and ambient temperatures were mild. In summer they foraged primarily on shrubs and sought shade in the saltcedar and mesquite thickets near the river. Honey mesquite beans were heavily used in late June and July as pods ripened and fell to the ground.

Fecal diet analysis showed an annual intake of 4% grasses, 30% forbs, and 61% shrubs (5% unknowns). Woolly Indian wheat and blue palo verde were the two most important food items. Annual home range size was 30 km^2 (12 mi^2), with no significant difference between jacks and jennies. Only one jack displayed territoriality during June through August; he defended 0.5 km^2 (0.2 mi^2; Woodward 1976).

Colts formed 23% of the population. If this value represents recruitment every 16 to 18 months, the population could double every 5 years. A young-herd age structure combined with virtually no predation allows conditions for a rapidly growing population. If the population is left to grow unchecked, it is a threat to the fragile desert environment.

Bill Williams Mountains, Arizona

These mountains abut the Bill Williams River just east of Parker Dam, which is at the lower end of Lake Havasu. This burro population showed similar movement patterns as those in the Chemehuevi Mountains during winter and summer months. A sharp contrast was that they watered primarily at night, which was thought to be a product of persecution by local ranch hands (Seegmiller 1977).

Burros predominantly used foothills during all seasons, but washes were frequently used from June through October. During the summer months burros retreated to the foothills during the day and used the riparian vegetation and cultivated fields along the Bill Williams River at night.

Fecal diet analysis showed an annual intake of 23% grasses and sedges, 33% forbs, and 40% browse (4% unknowns). A total of 49 plant species were eaten by burros with woolly Indian wheat and palo verde being the primary forage.

Mean monthly herd size varied little from the annual average of 4.7 animals. The most stable relationship was jenny/foal, which often persisted for 2 years unless the older colt was a jack. Young jacks frequently banded into smaller bachelor groups.

Mean annual home range size for adult burros was 19.2 km^2 (7.4 mi^2), which was significantly smaller than that in the Chemehuevi Mountains. The presence of cultivated fields in the Bill Williams alluvial floodplain may have reduced travel requirements to secure forage. There was no significant difference between home range sizes of jacks and jennies.

Five jacks showed reduced home range sizes in summer, but territorial defense was not observed.

Colts also formed 20% to 23% of the population in the Bill Williams Mountains. Dead palo verde trees from heavy foraging by burros were more noticeable in the Bill Williams Mountains than in the former study area. Again, unless populations are managed and controlled, indications are that these fragile desert ecosystems will be destroyed.

The above examples in habitat use and population dynamics are probably a good general representation of what is occurring in all burro populations along the lower river. In these fragile desert mountain ranges (average annual rainfall is about 7.5 cm [3 inches] and highly variable from year to year), the annual plant productivity is low. When winter rainfall is average or better there is high forb productivity, lessening the forage removal and damage to shrubs, especially palo verdes. When there is little or no winter rainfall palo verdes get little respite. Unfortunately, these trees are very brittle and appear not to have evolved with a large herbivore possessing both upper and lower incisors. Consequently, when they are browsed by burros whole limbs may be broken off and only small amounts consumed.

12.9 CARNIVORES

A number of carnivores occupy the riparian habitats along the Colorado River. These range in size from the Yuma puma (Felis concolor browni) to the spotted skunk. Intermediate sizes include the coyote, bobcat, gray fox, kit fox, raccoon, badger, and striped skunk. In general, little is known of the biology of many of these species along the lower Colorado River. The dense vegetation and expense in studying individual species has prevented extensive data collection. Some radiotelemetry was attempted on coyotes, but this proved to be difficult at best.

Other study approaches were used and proved valuable to a degree, but all had their limitations without the added dimension of radio-tracking locations. Monthly scat collections in major community and structural types provided valuable biological information on relative coyote densities in specific habitat types and seasonal food habits. These then, in turn, could be correlated with small mammal numbers, avian numbers, and plant food availability in each habitat type. However, this approach provided little information relative to smaller carnivores, and the paucity of observational records provides little insight into their biology.

Yuma Puma

This large felid has an interesting taxonomic and historical record on the lower Colorado River. The first recorded scientific specimen was an adult male collected by Herbert Brown in 1901, 19 km (12 mi) south of Yuma, AZ. This type specimen was originally described by Merriam (1901) as a race of mountain lion (Felis aztecus browni), after the original collector. Nelson and Goldman (1929) revised the puma group into one species known as Felis concolor, the Yuma puma being recognized as F. c. browni.

Though the species has official recognition and has special Federal status, its taxonomic validity remains questionable. Between 1903 and 1929 a total of nine specimens were collected, five in Arizona, three in Baja California, and one in California. The paucity of specimens along with the variability of the taxonomic characters makes subspecific certainty difficult at best.

Distribution. Hall (1981) shows the distribution of this race extending south from Las Vegas, NV, on either side of the Colorado River to the Gulf of California. The east and west boundaries range from a few miles from the river at the northern limits to about 161 km (100 mi) east of the river in Sonora, Mexico. Only six of nine specimens recorded were collected near the river and the other three came from the Hualapai Mountains in northeastern Arizona. Reports of the species since 1969 indicate 37 records of tracks and actual sightings, with the majority of these being along the river (Duke et al. 1987).

State and Federal status. This subspecies is on the list of Arizona threatened native wildlife and became a candidate for endangered status in December 1982 (Federal Register 1982). It was listed as a Category 2 species, indicating that the listing is possibly appropriate, but that more biological research is needed to validate the status of the taxon.

Habitat. Riparian habitats along the lower Colorado River appear to be essential to the existence of this large carnivore. The faunally depauperate deserts, that are extensive and lateral to the river, do not harbor enough prey to sustain a predator of this size. The exceptions are habitats of large mountain masses that have enough elevation and rainfall to support oaks (*Quercus* spp.) and conifers. Even the lush and once extensive riparian communities probably never supported high densities of pumas. Conversion of riparian habitats to urban and agricultural lands has significantly reduced available habitat for this species.

Exactly what habitats were used can only be surmised, but the cottonwood-willow gallery forests must have been important to these animals as cover in the capture of deer and other large vertebrates. All habitats were probably used as hunting areas and space to roam. Grinnell (1914) listed this species as having maximum abundance in the cottonwood-willow association.

Bobcat

Individual bobcats and their tracks are frequently observed in all community and structural habitats in riparian habitats. A number of individuals have been trapped by professional trappers involved in reducing predation on domestic sheep. Grinnell (1914) and his party trapped two near Needles during their survey.

Coyote

Many studies have shown that coyotes have a diverse diet (Sperry 1941; Murie 1945; Gier 1957; Korschgen 1957; Gipson 1974; Andrews and Boggess 1978; Berg and Chesness 1978; Kleinman and Brady 1978). The proportion of foods in the diet varies in relation to local and seasonal availability (Sperry 1941; Fitch 1948; Ferrel et al. 1953; Fichter et al. 1955; Gipson 1972). Food habits data for 5 years presented by Anderson and Ohmart (1984b) support the above consensus.

The following items were reported in coyote scats collected along the lower Colorado River over a 5-year period: 19 mammalian species, 20 plant species, 2 bird species, 2 reptilian species, eggshell remains, 9 orders of arthropods, unidentified fish, and miscellaneous items such as trash, leather, charcoal, gravel, and shot.

Compared with food frequencies in other food habit studies, percent frequency of occurrence of rabbits, rodents, deer, and livestock was lower in the present study. However, a majority of other studies identified all mammalian species. During the river study, unidentified mammals composed the largest category of mammalian foods (33%). Rabbits and rodents were the most frequently identified mammals, but were low compared to other studies. It is likely that rabbits and rodents were most frequent in the unidentified mammalian group. Deer and livestock were much less frequent. Plants were more frequent in this study compared with other studies.

Plant materials consistently were important in the diet, especially honey and screwbean mesquite. Saltcedar was frequently found in scats, but it apparently was a by-product of coyotes consuming it in animal fur. Agricultural crops also were important in some years. Sixty-eight items were identified in the total diet; of these, 24 were considered typical foods. The diversity of food ranged from rodents and rabbits to honey mesquite and melons to crayfish and beetles (Anderson and Ohmart 1984b). Principal foods, (volume/frequency ratios) were mammals, screwbean mesquite, and honey mesquite. Among mammals the white-throated woodrat, rabbit, and unidentified rodent all had high ratios.

Peak consumption of mammals and birds by coyotes corresponded to the seasonal population peaks of these prey. It also corresponded to the coyote breeding season. From the examination of reproductive tracts of coyotes collected in 13 Western States, including Arizona, Hamlett (1938) found that the coyote breeding season was under way by February. Observations of a small captive coyote population in a desert-vegetated enclosure at Arizona State University indicated that breeding begins in late January or early February. Gestation is 60-63 days (Gier 1957; Kennelly 1978). Litters were born to the captive coyotes in early April.

Coyote reproductive success depends on favorable environmental conditions, including food availability (Murie 1940; Gier 1957, 1975; Clark 1972; Nellis and Keith 1976). Clark (1972) found that the coyote reproductive rate was correlated with jackrabbit density, a major food item for those coyotes. He suggested a possible effect of food availability on ovulation. Rodents and rabbits were mainstay foods for coyotes on the lower Colorado River. Peak abundance and consumption of mammals (and birds) corresponded to the coyote breeding season when food availability was of critical importance to reproductive success.

Coyote habitat associations were determined by examining the number of scats/km of each plant community sampled. Scats were most abundant in honey mesquite habitats in 1975, but in 1976 and 1977 were most abundant in screwbean mesquite habitats.

Coyotes consumed livestock and agricultural crops, but these appeared as items adding to the diversity of foods consumed and did not rank as principal food items. Other studies have reported that coyotes resort to livestock consumption when abundances of other major foods, such as rabbits and/or rodents, are low. Livestock consumption by coyotes in this region did not correspond to (and therefore did not offset) decreased rodent consumption. During decreased rodent abundance coyotes ate more mesquite pods, preyed more heavily on rabbits, and consumed a greater diversity of foods, such as arthropods, reptiles, and plants. These data suggest that coyotes in this region did not prey heavily on livestock, that is, sheep that grazed in the valley during winter months. This is not to say that some coyotes did not kill and eat sheep, but generally the coyote population relied most heavily on natural foods.

Cottontail rabbits, small rodents, and mesquite fruits were the most important components in the coyote diet. Rabbits and rodents are to some degree pests to agriculture (Eadie 1954; Gier 1957). Coyote dependence on rabbits and rodents may benefit farmers. Although rodent densities, other than pocket gophers, were small in agricultural land, rabbit populations were large (Anderson and Ohmart 1982a).

Major food items for coyotes were abundantly available in the region. Stands of honey mesquite were prolific (millions of pods per 40 ha [100 acres]) in the lower Colorado River Valley, and small rodents and cottontail rabbits showed an extended breeding period (due probably to the mild regional climate). Native riparian habitats harbor these foods. Therefore, if adequate native habitat is preserved, coyote populations could be sustained in those areas and would present little threat to farms or livestock.

Kit Fox

This fox is seldom, if ever, seen in the riparian habitats, but dense vegetation may prevent observation. Grinnell (1914) stated "...no evidence at all was forthcoming to show that kit foxes ever visit the river or bottomlands." He characterized this species as an element of the upland desert fauna in sandy soils near kangaroo rat colonies. If kangaroo rats have recently moved in to occupy mesquite terraces, perhaps kit foxes have followed. They are known to occupy desert washes elsewhere in Arizona.

Gray Fox

The gray fox is a relatively common but rarely seen resident of dense riparian habitat. Some scat samples of this species were collected along sample lines, but these were too few to provide meaningful results. Grinnell (1914) and his party collected nine specimens during their studies and reported the species as widespread.

Raccoon

The raccoon was considered common and even a "nuisance" to beaver trappers along the lower Colorado River in the late 1800's, early 1900's, and into the 1950's (Grinnell 1914; Hoffmeister 1986). Presently, raccoons occur throughout the system but are rarely observed. Hoffmeister (1986) comments that raccoons do not appear to be nearly as numerous throughout Arizona as they were historically. Raccoon footprints indicate their presence, especially in the Bill Williams Delta and directly adjacent to the main river channel where extensive mudflats occur. Aquatic invertebrates, especially crayfish, contribute significantly to the raccoon's diet as do large terrestrial invertebrates and small aquatic and terrestrial vertebrates. The raccoon is most frequently encountered at water's edge in emergent or terrestrial riparian plant communities.

Striped Skunk

This common resident of riparian habitats is frequently observed in late evening, night, and early morning in dense habitats near water. Casual observations away from human habitations indicated a strong reliance on insects and other invertebrates, although small mammals are probably readily eaten when captured. Near human habitations the species searches through and feeds heavily on garbage and possibly rodents in garbage piles (Ohmart, pers. obs.). Eight specimens were taken by Grinnell (1914) and his party. Those caught were in mesquite, screwbean, willow, and arrowweed tracts.

Spotted Skunk

This small nocturnal skunk is seldom seen in the study area, but may be more abundant than records indicate. Three different individuals were observed in the Cibola Reach on the California side in May 1972 (Ohmart, pers. obs.). These animals were hunting insects in openings around dense arrowweed and quail bush stands. Grinnell (1914) wrote they were "not common" as indicated by trapping efforts. Tracks were observed near Needles and a specimen was taken in the arrowweed belt within 91 m (100 yd) of the river close to Pilot Knob in California.

Badger

Most sightings of this species have been in honey mesquite or similar habitat that is sparsely vegetated. Specimen records (Grinnell 1914; Hoffmeister 1986) indicate that the species occurs throughout the riparian study area in relatively low densities.

12.10 LISTED SPECIES AND SPECIES OF SPECIAL INTEREST

At present, there are no Federal- or State-listed endangered mammals on the lower Colorado River. There are, however, several species of special concern monitored by both California and Arizona. The river otter, of interest to Arizona, and the Yuma puma and desert bighorn sheep, of interest to both States, have been discussed in depth previously in this chapter.

In addition to the above species, California lists Arizona cave myotis (Myotis velifer), California leaf-nosed bat (Macrotus californicus), and Colorado River cotton rat (Sigmodon arizonae plenus) as species of special concern (Williams 1986). Sonoran beaver (Castor canadensis repentinus or C. c. frondator; see Hoffmeister 1986) and the Colorado Valley white-throated woodrat (Neotoma albigula venusta) are listed as candidate species of special concern, but these species appear to have few imminent threats to their population levels. Arizona collects data on threatened native wildlife including southern yellow bat (Lasiurus ega). Both States consider Arizona myotis (Myotis occultus), pocketed free-tailed bat (Taderida femorosacca), and hispid cotton rat (Sigmodon hispidus eremicus) as species to monitor.

Both Arizona myotis and Arizona cave myotis colonies have been severely reduced during the last few decades (Williams 1986). Both species feed in and over riparian vegetation and the river proper. The Arizona myotis has its colonies located under bridges, in old cottonwoods, and in old attics. The Arizona cave myotis most commonly roosts in caves and mine shafts in the upland desert, but forages nightly over the same or similar habitats as the Arizona myotis (Vaughan 1959). Both species have suffered serious declines in number of colonies and average colony size; these declines are partly due to intense human disturbance (Williams 1986). In addition, heavy insecticide use has been implicated in causing declines in both species, as they both forage directly over sprayed areas on the lower Colorado River (Geluso et al. 1976; Fenton and Barclay 1980; Williams 1986). Both myotis species are of highest priority for designation as State-listed endangered species in California. The Arizona myotis population on the lower Colorado River is the only known population in California and appears to be separated by at least 322 km (200 mi) from the next known colonies to the east (Hoffmeister 1986).

Three species of bats associated more with upland deserts are of interest to California or Arizona. The pocketed free-tailed bat is a little-known species and has a spotty distribution throughout the Southwest. This species inhabits rocky cliffs and slopes, with a colony known along the cliffs adjacent to the Bill Williams River (Hoffmeister 1986). It also has been taken near the mouth of the Colorado River (Williams 1986). California leaf-nosed bat is a low-desert species and is apparently very sensitive to disturbance of maternity roosts. This species has declined principally from the coastal basins of southern California but may be stable elsewhere; few data exist on the status of the California leaf-nosed bat along the lower Colorado River. The western yellow bat is known only from residential areas in and around Yuma where Washington palms (*Washingtonia filifera*) are cultivated. There is at present no apparent threat to the population, though its status is not well understood. None of these species are of high priority to management agencies, nor are these species well known along the lower Colorado River. While changes in riparian habitats are unlikely to affect them, increasing use of desert areas may disrupt maternity colonies.

Two species of cotton rats are represented on the lower Colorado River by isolated populations (for taxonomic treatment see Hoffmeister 1986). California lists the Arizona cotton rat, as it is apparently nearing extirpation on the California side, though it is still common in appropriate habitat on the Arizona side. This population was known to occur from near Needles south to near Bard, CA, but it is presently not known from any locality on the California side. However, Anderson and Ohmart (1982b) report cotton rats (species unknown, but probably Arizona) as common on their revegetation site near Cibola National Wildlife Refuge. Arizona collects data on the hispid cotton rat, as it is confined to the Colorado River from the Gila River confluence south. This species is common and possibly expanding as agriculture and associated unlined canals support emergent vegetation. The hispid cotton rat also has recently spread into the Imperial Valley of southern California and is common near marshes and in agricultural fields, especially milo and corn (Anderson and Ohmart 1982a; Williams 1986). Both these species have apparently increased, at least in distribution, since the turn of the century, but they represent isolated populations and should be monitored. Their relationship and distribution are of interest to systematists and ecologists (see Hoffmeister 1986; compare with Botta's pocket gopher in this chapter).

Riparian habitats are important to a large number of mammal species as reported for all other vertebrate groups. Extensive manipulation of riparian and aquatic habitats is associated with dramatic declines for most of these species. Future riparian habitat degradation will continue to affect these populations. Other threats include disturbance of desert bat maternity roosts and various impacts affecting desert bighorn sheep.

CHAPTER 13. MANAGEMENT PRACTICES AND RECOMMENDATIONS

13.1 RIVER MANAGEMENT

The many laws that govern the operations of the lower Colorado River mandate efficient water transport and delivery to users, flood control, navigation, and recreation (including sports fisheries). Protection of wildlife, native fisheries, and native riparian vegetation were rarely, if ever, considered in managing operations on the river until passage of the National Environmental Protection Act of 1969 (NEPA), Fish and Wildlife Coordination Act of 1958 (FWCA), the Endangered Species Act of 1973 (ESA), and Clean Water Act of 1977 (CWA). Conservation agencies and private environmental groups have effected some minor changes in operations and have been able to commit water management agencies to offset some impacts with mitigation. Despite these efforts, it is clear that conservation issues will continue to be low on the management priority list on the lower Colorado River.

The U.S. Bureau of Reclamation (BR) is responsible for water management of the lower Colorado River. BR's primary function is to transport and distribute water as efficiently as possible, all too often with little consideration of environmental consequences. Past water management activities, such as construction of dams, channelization (straightening) of the river, and addition of riprap to armor portions of modified stretches have all had highly negative effects on the native fauna and flora of the system (Minckley 1979; Anderson and Ohmart 1984b). Clearing extensive floodways also has had severe adverse impacts on riparian vegetation and associated wildlife. In addition, most backwater areas are in danger of almost totally losing water circulation from the mainstream. These impacts will have to be mitigated for to avoid further degradation of terrestrial and aquatic habitats. Finally, positive management activities will have to be undertaken to improve or protect the remnants of the lower Colorado River's natural environment.

Sixty-nine vertebrate species have been recognized as needing some sort of protection along the lower Colorado River (Table 61). Varying levels of protection for some species are afforded through endangered or threatened status by Federal, California, and Nevada laws. Lower levels of legal protection are provided to species listed as experimental, rare, and protected in Federal, California, and Nevada statutes, respectively. Such legislation may provide the impetus needed for habitat protection and improvement.

The Federal Government maintains a list of candidate species in the Notice of Review, published periodically in the Federal Register. Candidate species are afforded no legal protection, but are, or have been, considered for Federal Endangered or Threatened status. Category 1 is for species with enough status information to warrant listing. Category 2 indicates that not enough information exists to warrant listing and status

Table 61. Summary of State and Federal species of special concern with populations on or near lower Colorado River. E = endangered; T = threatened; R = rare; P = protected; Cat-1 = awaiting Federal listing; Cat-2 = under study for Federal listing; Cat-3 = presently not considered to be threatened nationally; SC-1 = high priority species of special concern; SC-2 = second priority species of special concern; SC-3 = third priority species of special concern; SC-4 = candidate species of special concern; G-1 = extirpated recently; G-2 = threatened with extirpation; G-3 = potentially threatened in near future; and G-4 moderate threat to habitat(s) but presently no decline. Listed threats are other than wholescale habitat loss. Sources: (1) Endangered Species Act of 1973: Endangered and Threatened Wildlife and Plants July 27, 1983 (50 CFR 17.11 and 17.12), (2) Threatened Wildlife in Arizona (1988), Arizona Game and Fish Commission, (3) 1986 Annual Report on the Status of California's Threatened and Endangered Plants and Animals, California Department of Fish and Game (February 1987), (4) Remsen (1978), (5) Williams (1986), and (6) Nevada Administrative Code (October 1986), Rare and Endangered Species.

Class/species	Category				Potential and/or actual threat
	Federal	Arizona	California	Nevada	
Invertebrates					
MacNeill sooty-wing skipper	Cat-2	—	—	—	Loss of *Atriplex lentiformis* for reproduction
Subtotal	1	0	0	0	
Fishes (N = 7)					
Bonytail chub	E	G-2	E	E	Reproductive failure; depredation on young by exotic fish
Roundtail (Colorado River) chub		G-3			No immediate threats
Woundfin	E	G-2		E	Reproductive failure; depredation on young by exotic fish

(Continued)

Table 61. (Continued)

Class/species	Federal	Arizona	California	Nevada	Potential and/or actual threat
	Category				
Colorado squawfish	E	G-1	E	E	Reproductive failure; spawn runs halted (?)
Razorback sucker	Cat-2	G-2	E	P	Reproductive failure; depredation on young
Desert pupfish	E	G-1	E		Depredation on young by exotic fish
Gila topminnow	E	G-2	—	—	Depredation on young by exotic fish
Subtotal	6	7	4	4	
Amphibians (N = 1)					
Lowland leopard frog	Cat-2	G-4	—	—	Depredation by bullfrog and exotic fish on larvae and small adults
Subtotal	1	1	0	0	
Reptiles (N = 6)					
Desert tortoise	Cat-2	G-4	SC-2	R	ORV; collecting; canals bisecting dispersal routes
Colorado Desert fringe-toed lizard	Cat-2	G-4	SC-3		ORV; conversion of habitat to agriculture
Mohave fringe-toed lizard	Cat-2	G-4	SC-3		ORV; conversion of habitat to agriculture
Flat-tailed horned lizard	Cat-2	G-3	SC-3		ORV; conversion of habitat to agriculture

(Continued)

Table 61. (Continued)

Class/species	Federal	Arizona	California	Nevada	Potential and/or actual threat
	Category				
Gila monster	Cat-3C			R	Collecting
Mexican garter snake	Cat-2	G-4			Depredation of young by bullfrog
Subtotal	6	5	4	2	
Birds (N = 41)					
Western grebe			SC-4		Recreational disturbance to breeding
Clark's grebe		G-4	SC-4		Recreational disturbance to breeding
Double-crested cormorant			SC-2		Toxins in food; disturbance of nesting colony
American bittern		G-4			No immediate threats
Least bittern		G-4	SC-3		Flooding resulting in nest disturbance
Great egret		G-3			Disturbances to nesting; toxins in food
Snowy egret		G-4			Disturbances to nesting; toxins in food
Black-crowned night-heron		G-4			Disturbances to nesting; toxins in food
Fulvous whistling-duck	Cat-2		SC-1		Disturbance to breeding habitat
Osprey			SC-2		Toxins in food
Bald eagle	E	G-2	E	E	Toxins in food
Northern harrier			SC-2		Pesticides in agriculture

(Continued)

Table 61. (Continued)

Class/species	Federal	Arizona	California	Nevada	Potential and/or actual threat
Cooper's hawk			SC-3		Complete loss of breeding habitat
Common black-hawk		G-4			Toxins in food; lack of breeding habitat
Harris' hawk			SC-1		Complete loss of breeding habitat
Swainson's hawk	Cat-3C		T		Pesticides in agriculture
Merlin			SC-1		Pesticides in agriculture
Peregrine falcon	E	G-4	E	E	Pesticides in agriculture; toxins in waterfowl
Black rail	Cat-1	G-2	T		Flooding change to habitat; toxins in food
Yuma clapper rail	E	G-3	T		River management activities; toxins in food
Black-necked stilt		G-4			Disturbance to nests
Yellow-billed cuckoo		G-2	SC-1	E	Complete loss of breeding habitat
Elf owl			E		Near complete loss of cavities
Burrowing owl			SC-2		Pesticides; concrete-lining canals
Long-eared owl			SC-2		Restriction of cavities
Gila woodpecker			SC-2		Restriction of cavities; disturbance from European starlings
Gilded northern flicker			SC-1		Restriction of cavities

(Continued)

Table 61. (Continued)

Class/species	Category: Federal	Arizona	California	Nevada	Potential and/or actual threat
Willow flycatcher	Cat-2	G-2	SC-1		Complete loss of breeding habitat; cowbird parasitism
Vermilion flycatcher			SC-1		Complete loss of breeding habitat
Brown-crested flycatcher			SC-3		Restriction of cavities; starling interference
Black-tailed gnatcatcher			SC-2		No immediate threats
Crissal thrasher			SC-3		No immediate threats
Sprague's pipit		G-4			No immediate threats
Bell's vireo	Cat-3C		SC-1		Near complete loss of breeding habitat; cowbird parasitism
Lucy's warbler			SC-4		No immediate threats
Yellow warbler			SC-2		Near complete loss of breeding habitat; cowbird parasitism
Yellow-breasted chat			SC-2		No immediate threats
Summer tanager			SC-2		Complete loss of breeding habitat
Northern cardinal			SC-3		No immediate threats
Blue grosbeak			SC-4		No immediate threats
Abert's towhee	—	—	SC-4	—	No immediate threats
Subtotal	8	15	34	3	
Mammals (N = 12)					
California leaf-nosed bat	Cat-2		SC-2		Mining disturbance of maternity roosts and day roosts

(Continued)

Table 61. (Concluded)

Class/species	Federal	Arizona	California	Nevada	Potential and/or actual threat
	Category				
Cave myotis	Cat-2		SC-1		Mining disturbance of maternity roosts; loss of foraging habitat; pesticides
Arizona myotis			SC-1		Disturbance of maternity roosts; loss of foraging habitat; pesticides over agriculture
Southern yellow bat		G-4			Disturbance of native palm trees, including pruning in suburban areas
Townsend's big-ear bat	Cat-2		SC-2		Disturbance of maternity roosts
Pocketed free-tailed bat			SC-2		Disturbance of isolated roosts
River otter	Cat-2	G-2			Stream modification; trapping and other conflicts with man
Mountain lion (Yuma puma)	Cat-2	G-2	SC-1		Bounties; possibly lowered food resources; loss of cover
Beaver			SC-4		Stream modification; cement-lined canals; sewage disposal; trapping
White-throated woodrat			SC-4		No immediate threats
Arizona cotton rat			SC-1		Water table drawdown affecting marsh vegetation
Desert bighorn sheep		G-3		P	Competition with burros and disease
Subtotal	5	4	9	1	
TOTAL	27	32	51	10	

of these species is under study. Category 3 is for species no longer considered for listing and includes extinct species (3A), species no longer valid taxonomically (3B), and species that are not presently considered threatened nationally (3C).

California also has instituted a program of Species of Special Concern, affording no legal status, but attempting to protect species before they require legal protection. Four levels for Species of Special Concern were recognized: (1) highest priority, (2) second priority, (3) third priority, and (4) candidate sensitive species. Highest priority species may soon face extirpation in California. Second priority species have suffered declines through a large portion of their distribution in California. Third priority species are those that occur locally within the State and are not presently declining but should be monitored. Candidate sensitive species include those for which data may suggest listing, but require additional study.

Arizona provides no legal protection for species, but maintains a List of Threatened Native Wildlife for setting management priorities in cooperation with Federal and other government agencies. Group 1 includes species extirpated from Arizona in recent history. Group 2 are species or subspecies whose continued presence in Arizona is now in jeopardy. Group 3 includes species whose status could be in jeopardy in the foreseeable future. Finally, Group 4 includes species with moderate threats existing to important habitats, but no substantial declines have been documented. Arizona's list will be revised during 1988 and will involve changes in status definitions and some species listed; this new list was not available for inclusion here (Arizona Game and Fish Commission 1988).

Fifty-two of the 69 species are affected by disturbance to aquatic, emergent, and riparian habitats. The importance of these habitats is unequivocal, given the large number of species in need of some protection by at least one State or the Federal Government. The future for aquatic and native terrestrial riparian habitats is bleak, unless present management practices are drastically altered by the State and Federal agencies responsible for managing the lower Colorado River and its associated aquatic and riparian resources. Native fishes have virtually been eliminated, some sports fishes are declining, and many native riparian plant and animal species have been extirpated, or nearly so, with little hope of return to stable populations. Future management practices for the remaining native flora and fauna should include strong conservation practices for remaining habitats. Such conservation is unlikely, however, unless there are changes in current attitudes and policies governing river management.

13.2 AQUATIC RESTORATION

At present, there are few attempts to restore aquatic habitats with respect to the native ichthyofauna on the lower Colorado River. Reintroduction of razorback sucker is the primary action now being undertaken, with the possibility of reintroduction of Colorado squawfish in the near future. Successful reestablishment of native fishes will not be possible without some level of restoration of the natural aquatic environment and control of introduced fish species.

One possibility for aquatic habitat restoration is the establishment of semiartificial ponds and lakes that may serve as permanent holding ponds for native fishes (Minckley, pers.

comm.). Presently, razorback suckers are being held in ponds near Blythe and Niland, CA, to allow size increase before being released into the Colorado River (Langhorst 1987b). Precedents for semiartificial habitats exist, with one pond supporting desert pupfish and Gila topminnow at the Boyce-Thompson Southwestern Arboretum, Superior, AZ, and another pond proposed to support many of the native fish species on the Hassayampa River Nature Conservancy Preserve, Wickenburg, AZ.

The building of semiartificial ponds and lakes may entail soil excavation to the water table, allowing subsurface water seepage. Several native species may actually breed successfully in such situations, especially if nutrients are added and stable phytoplankton and zooplankton, benthic invertebrate, and macrophyte crops are allowed to develop.

Intensive monitoring will be needed, however, to keep exotic fish out of these habitats and to determine if such situations can actually benefit the many native fish involved. Maintaining an exotic-free environment may be nearly impossible if bait fishermen are allowed access to such structures. In addition, exotic fish eggs are often dispersed by waterbirds moving from one aquatic habitat to another. Solutions to these problems may be found through research to control exotics. There remain many opportunities to restore native fish communities, despite the problems associated with semiartificial ponds. Such efforts may eventually allow better understanding of how to successfully reintroduce native species into riverine environments.

13.3 POTENTIAL FOR REVEGETATION

With careful planning, revegetating areas for wildlife can be accomplished in a relatively short time (Anderson and Ohmart 1982b; Figs. 37, 38, 39, 40, 41). Within five years a gallery forest with canopy height >15 m (>50 ft) can be created along the lower Colorado River through knowledgeable and aggressive management. Dams have virtually eliminated flooding, which is essential to cottonwood and willow germination. Therefore, revegetation with native plant species soon may be the only way to ensure the survival of wildlife dependent on mature stands of cottonwoods and willows.

Many Federal and State agencies have proposed revegetation, during the last 15 years, to mitigate against unavoidable habitat losses to wildlife. Most of these efforts have been unsuccessful because of inadequate funding and lack of knowledge, planning, and logistical support. In general, agencies with adequate budgets and logistical support have repeatedly demonstrated a lack of concern for success, while those agencies advocating revegetation have relatively small budgets.

Revegetation, if carried out properly, can be quite successful. Anderson and Ohmart's (1982b, 1984a) efforts on a 30-ha (75 acres) produced high-quality wildlife habitat at a cost of $9,000 to $10,000 per ha ($3,600-$4,000/acre). No other revegetation efforts begin to approach the success of this project, either in growth rate of trees or survival. Smaller (≤10 ha [≤25 acres]) revegetation efforts have provided some low-

Figure 37. Clearing a site of plant competitors (especially Bermuda grass and saltcedar) is essential for a successful revegetation project as at Cibola National Wildlife Refuge. Photo by J. Disano.

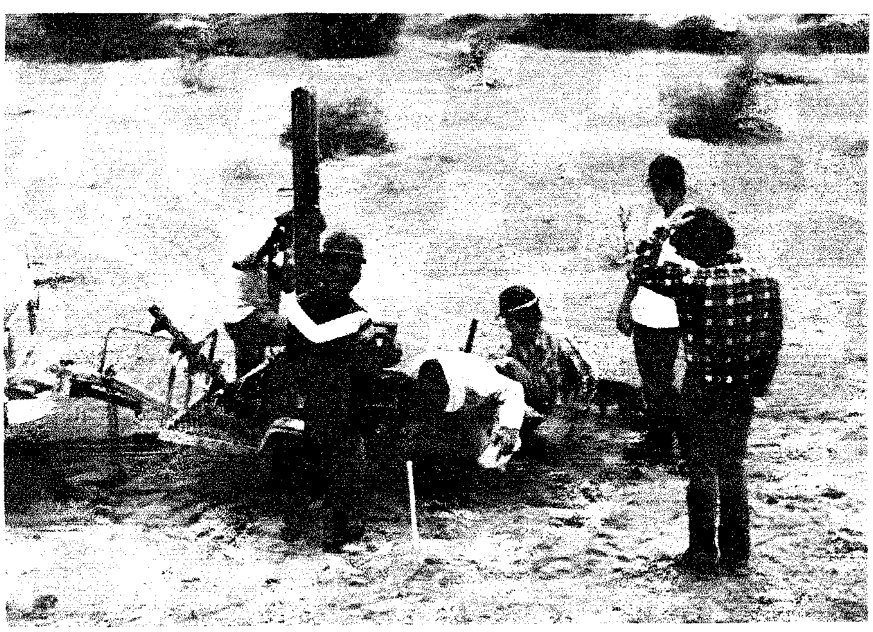

Figure 38. Augering holes to the water table and collecting soil, water, and salinity data are all essential steps in determining the growth potential of native riparian trees and shrubs. Photo by J. Disano.

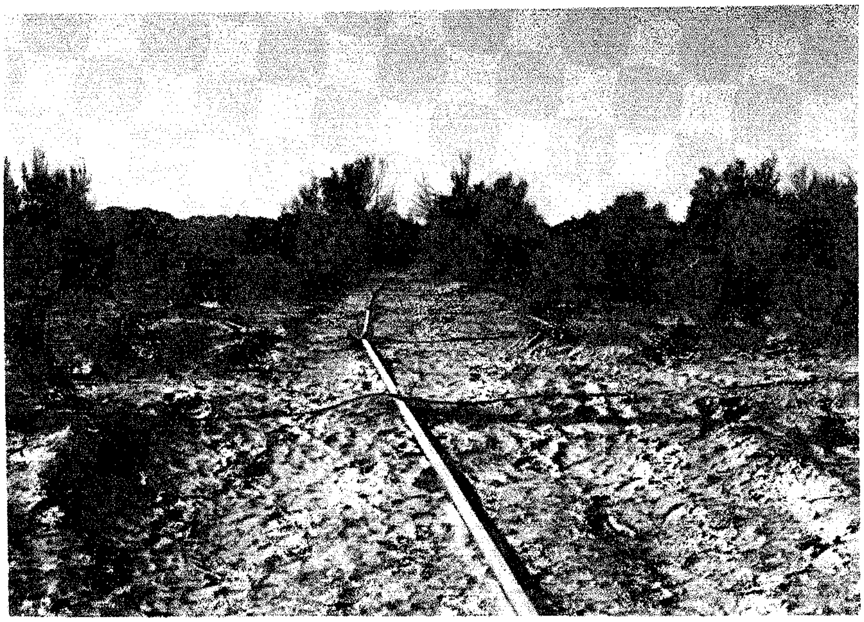

Figure 39A. Above-ground drip irrigation is the least expensive and most efficient means for watering trees. Special care is needed for tracking duration and amount of irrigation on trees and shrubs in accordance with physical parameters. Photo from Cibola National Wildlife Refuge (1979) by J. Disano.

Figure 39B. Same area as in (A) 1 year after planting (1981) of shrubs (mostly quail bush and inkweed). Photo by J. Disano.

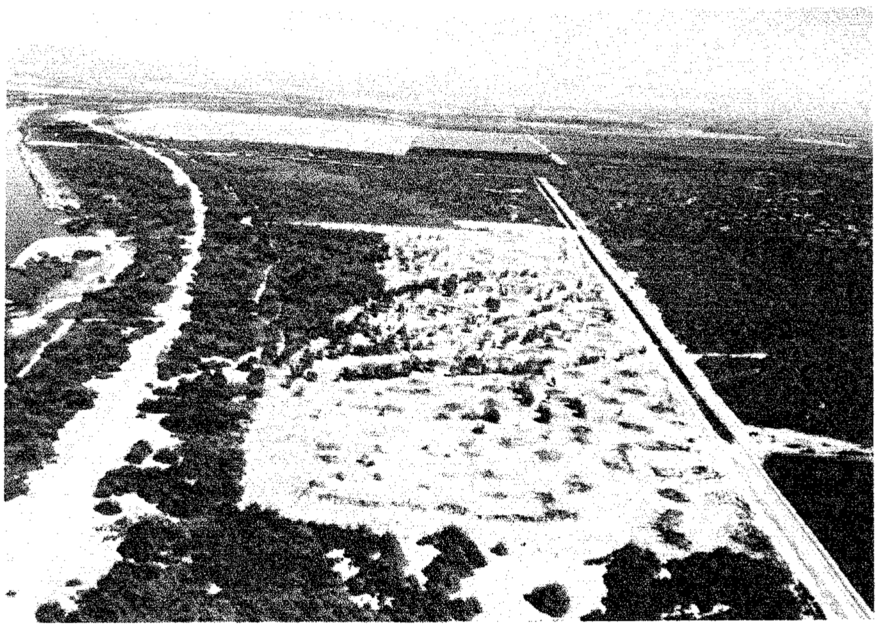

Figure 40A. Aerial oblique of Cibola National Wildlife Refuge revegetation site after clearing but before planting (1979). Photo by W. Deason.

Figure 40B. Aerial oblique of same site 1 year after planting (1981). Photo by R.D. Ohmart.

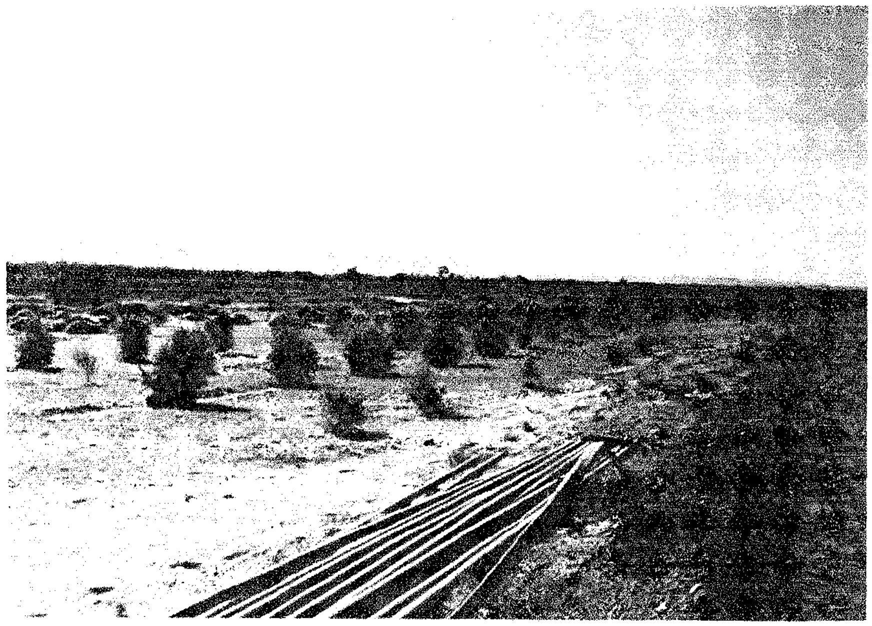

Figure 41A. Revegetation of cottonwoods on dredge spoil 4 months after planting. Holes were augered to water table. Photo (1979) by R.J. Dummer.

Figure 41B. Same trees 1.5 years after planting. Irrigation for most trees was terminated after 1 year. Photo (1980) by J. Disano.

Figure 41C. Same trees 3.5 years after planting. Photo (1982) by J. Disano.

Figure 41D. Same trees 5 years after planting. Photo (1983) by J. Disano.

Figure 41E. Same trees 8 years after planting. Photo (1986) by T.R. McMahon.

quality cottonwood-willow habitat for some declining bird species. However, small sites do not provide enough continuous habitat necessary for the recovery of all the wildlife species of concern. Both habitat quality and quantity appear to play important roles in attracting and holding species. Widely separated small plots are not adequate to accomplish the goals for which they were planned. Only large-scale, well-planned projects will provide the greatest benefits to wildlife (Figure 42).

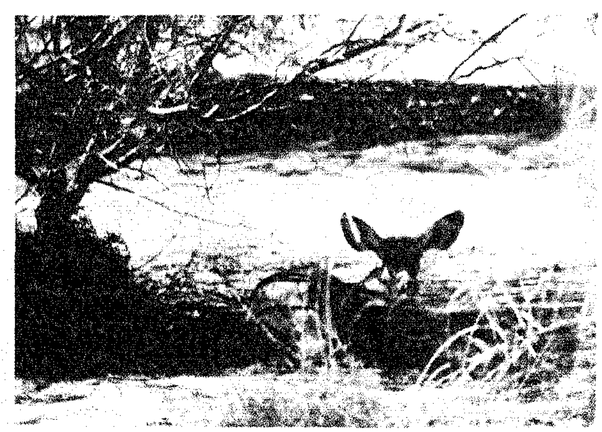

Figure 42. Mule deer using dredge-spoil revegetation site for foraging and bedding. Photo (January 1983) by J. Disano.

Most revegetation efforts have been implemented as mitigation for habitat losses due to water management construction activities. Revegetation done solely for benefit to wildlife is usually considered too costly except when a species' survival is critical. Unquestionably, we have reached the critical stage in the status of many species along the lower Colorado River. Effective revegetation (gauged by achieving 90% or more of potential biomass production at the end of three growing seasons; Anderson and Ohmart, unpubl. data) must be the criterion in future revegetation efforts. This will only come about if agencies select contractors who have demonstrated capabilities to succeed in revegetation work. BR is the financial leader in these mitigation efforts as they are responsible for most of the habitat destruction. However, BR has been a poor leader in these efforts. The original habitats have been destroyed in construction activities, while the revegetation efforts can only be classified as mitigation disasters with trees dead or dying and tax dollars wasted.

A multitude of potential revegetation sites are available along the lower Colorado River. These include dredge-spoil sites and areas where saltcedar can be cleared and replaced with native vegetation. Government agencies overseeing water and wildlife management are largely supportive of revegetation proposals and the potential for reclaiming native habitats, but these bureaucracies have been extremely slow in adopting and demanding proven revegetation methods.

13.4 MANAGEMENT OF AGRICULTURE FOR WILDLIFE

Two major management prescriptions could greatly enhance wildlife use of agricultural areas. These are (1) maintaining or increasing the mosaic of riparian edge with agriculture and (2) weedy margins as cover and food resources for wildlife away from riparian edge situations. Unfortunately, neither of these prescriptions is likely to be carried out in the near future, unless farmers understand the economic value of hedgerows in controlling soil erosion, curtailing evaporative water loss, and reducing pesticide use. Generally, farmers are resistant to increasing weed, shrub, and tree hedgerows as they fear invading pests and increased water use from such habitats would negate any benefits provided.

There continues to be a need for research in at least two areas to further facilitate management of agricultural areas for wildlife. The first area concerns use of chemicals versus the possibility of biological control of pests. Use of pesticides is expensive not only in application but also through healthcare. The feasibility of surrounding agricultural areas with narrow corridors of native trees and shrubs as an alternative to pesticide use should be explored. These corridors have high value in attracting native wildlife, most which primarily feed on crop pests and weed seeds. Hedgerows of native trees and shrubs could reduce or eliminate the use of expensive pesticide applications. This would enhance agricultural areas for wildlife and at the same time reduce evaporative water loss and wind-eroded soils. Corridors of native trees and shrubs in agricultural areas only need to be 1.2 to 1.8 m (4 to 6 ft) wide to be effective (Conine et al. 1978) and would require little water and maintenance. In addition to the potential for reducing pesticides, fertilizers, and top-soil erosion, such corridors could provide private landowners with recreational and economic opportunities (e.g., hunting).

Possibilities for the reduction of pesticide use leads to the second area needing research. Some field types support more wildlife species than others. Although pesticide use is heaviest on some crops that are not used extensively by wildlife, it is not clear that pesticides are totally responsible for differences in wildlife use among field types; vegetation structural characteristics, food resources, or adjacent vegetation may also be involved. Biological control of pests may provide equal or increased yields while simultaneously reducing the need for expensive pesticide applications.

Economics appear to be the only way farmers will adopt more holistic approaches in agricultural practices. Holistic approaches are more ecologically balanced and call for less application of insecticides and herbicides. Thus, future research should be centered on alternatives to herbicide and insecticide use.

13.5 EDUCATION AND LEGISLATION

Only as the general public becomes more aware of the value of natural resources to our mental and physical health, especially to future generations, will true progress in conservation of natural resources become a reality. Progress has been made beginning in the 1950's as the American public has become more aware of the rapid disappearance of our natural resources. In part, this has been a lesson learned by watching the plight of Old World countries that have, in the name of progress, destroyed their natural resources, and from the sobering realization that our own natural resources are finite. Education is a slow process, but by concentrating on our nation's youth, we can instill a greater environmental awareness relative to the importance of conserving our natural resources.

There is still time to recover a small portion of those natural resources which remain along the lower Colorado River. It will only come about through intensive pressure from state, local, and private groups. Legislation to support this effort has been timely (e.g., NEPA, ESA), but Federal agencies have not responded as these laws dictate. Examples include the prolonged flooding of the best remaining cottonwood-willow stands by the Army Corps of Engineers in the Bill Williams River Delta. Its wildlife value (Rosenberg et al. 1982) was undisputed and its demise documented (Hunter et al. 1987). Much of this habitat was on the Havasu National Wildlife Refuge, yet the U.S. Fish and Wildlife Service did not prevent the U.S. Army Corps of Engineers from subjecting this habitat to prolonged flooding when it could have been saved and improved with planned releases.

Another example is BR's (1983) filing of an Environmental Assessment Report to do quarrying, stockpiling, riprapping, and dredging at numerous locations along the river under a Finding of No Significant Impact. Objections and concerns raised by other Federal and State agencies were not sufficient to prevent or adequately mitigate the adverse impacts of these activities. Subsequently, areas to be armored were overcleared and valuable habitats destroyed without proper documentation or adequate mitigation.

It would seem that aggressive adherence to existing environmental legislation would prevent further degradation of the Colorado River and its associated riparian ecosystem. New legislation that could be effective, if enforced, would be Federal classification of plant communities as endangered. Examination of those terrestrial animal species whose existence is in danger along the lower Colorado River quickly sorts into two groups: cottonwood-willow habitat specialists and a small group of other habitat specialists. The once thriving forest of cottonwood-willow that covered thousands of hectares (acres) along the river has been reduced to a few hundred hectares (acres) in less than 50 years. The last remaining contiguous stand of cottonwood-dominated habitat is 28 ha (70 acres)--a revegetated area on an old dredge-spoil site that was devoid of vegetation for over 20 years. This small island of habitat is currently not large enough to support all declining species, but there are hundreds of hectares (acres) of barren dredge spoil adjacent to it that have revegetation potential. Since revegetation efforts on similar sites have proven feasible, one can only wonder why Federal and State agencies are not supporting the expansion of this site. The current cottonwood-willow stand is about at threshold for attracting and holding many species that are near extirpation along the river, and expansion of this site would be highly beneficial to these species.

13.6 PROSPECTS FOR THE FUTURE

Anyone, after viewing the rapid and almost complete demise of the aquatic and riparian habitats along the Colorado River and its delta in just 50 years would be hard pressed to be optimistic about the next 50 years. Were it not for the Mexican water treaty, the Colorado River would be dewatered from the Morelos Dam south; just as the Rio Grande is from El Paso, TX, south 443 km (275 mi) to Presidio, TX, and the Salt River and Gila River are from Phoenix to the Colorado River. However, there is still an opportunity for improving the environmental quality of the lower Colorado River ecosystem through the combined aggressive action of Federal and State agencies. Without such action the Colorado River may simply become a barren ditch (possibly concrete-lined) for conveying contaminated water from reservoir to reservoir and, ultimately, to the desalinization plant near Yuma.

This downward trend in the lower Colorado River ecosystem will continue until private citizens and environmental groups exert enough pressure on State and Federal agencies and elected officials to address the problem. To date that concern has been scattered and unorganized. Unless pressure from environmentalists becomes focused and organized in the near future it will be too late for the few remaining natural resources along the lower Colorado River.

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APPENDIX A. CLASSIFICATION OF WETLANDS AND DEEP-WATER HABITATS

A.1 WETLAND CLASSIFICATION SYSTEM

Three wetland systems are represented on the lower Colorado River (Cowardin et al. 1979)[1] (Figure A-1). The Riverine System includes nonpersistent emergent wetlands and deep-water habitats (except dammed reservoirs) contained within a free-flowing channel. The Lacustrine System includes wetlands and deep-water habitats (including dammed reservoirs) situated in topographic depressions or dammed river channels lacking trees, shrubs, or persistent emergents. The Palustrine System, includes wetlands dominated by trees, shrubs, or persistent emergents; this system includes habitats that are referred to as riparian. The Cowardin et al. (1979) classification is hierarchical by subsystem, class, subclass, dominant biota, and modifier.

Many biologists believe that all wetlands associated with a river floodplain should be incorporated into the Riverine System because these wetlands are formed due to river flooding. Although river flooding is an important component in developing many Palustrine and Lacustrine wetlands, the maintenance of most of these habitats is usually determined by subsurface water. Lake surface elevation (not including reservoirs), stream flow, and the areal extent of riparian habitats are controlled, in part, by proximity and amount of groundwater (Reid and Wood 1976). Wetland systems on the lower Colorado River are influenced by groundwater levels and not by the Riverine System alone. Each of these three wetland systems is described below in context of the Cowardin et al. (1979) classification.

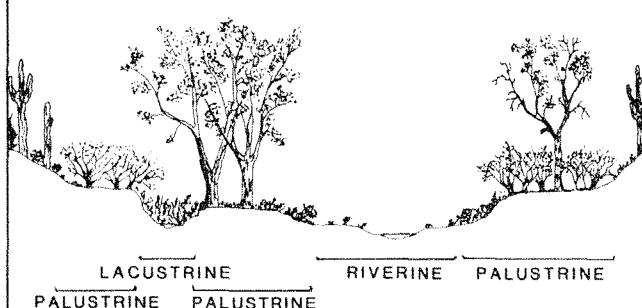


Figure A-1. Semidiagrammatic representation of wetland systems on the lower Colorado River and their designation as riverine, lacustrine, or palustrine. Adapted from Minckley and Brown (1982).

Riverine System

The Riverine System is bounded by desert upland, the channel bank (including natural and manmade levees), or by wetland dominated by trees, shrubs, and persistent emergents. Water in the Riverine System is usually flowing. Lower Perennial is the primary subsystem present on the lower Colorado River, within the United States, and is characterized by a low gradient and slow-moving water. Substrates of Lower Perennial Subsystems

[1]Citations are included in the text Literature Cited.

are mainly sand and mud. Other characteristics include an invertebrate fauna and flora composed mainly of species that reach maximum abundance in slow-moving water, with true planktonic organisms being common.

Some Upper Perennial Subsystem-like characteristics may be found immediately below dams where water temperatures remain cool to cold and water velocity, but not the gradient, is high. The substrate consists of rocks, cobble, and gravel with occasional patches of sand. The fauna and flora in Upper Perennial-like situations is characteristic of running water with few planktonic forms.

Subclasses and classes represented in the Riverine System include Cobble Rock Bottom, Cobble-Gravel, Unconsolidated Bottom, Sand Unconsolidated Bottom, Mud Unconsolidated Bottom, Organic Unconsolidated Bottom, Rooted and Floating Vascular Aquatic Beds, and Nonpersistent Emergent Wetland.

Lacustrine System

Like Riverine wetlands, the Lacustrine System is bounded by uplands or by wetlands dominated by trees, shrubs, or persistent emergents. Unlike the Riverine wetlands, Lacustrine wetlands are characterized by extremely slow-moving or stagnant water. Most Lacustrine wetlands on the lower Colorado River are reservoirs and are bound by a contour approximating the normal spillway elevation or normal pool elevation, except where Palustrine wetlands extend lakeward of that boundary. Besides reservoirs, backwaters (or oxbow lakes) and large artificial ponds are representative of Lacustrine wetlands on the lower Colorado River. Typically, where extensive areas of deep water exist there may be considerable wave action.

The Limnetic and Littoral subsystems of Lacustrine wetlands both occur on the lower Colorado River. Limnetic refers to all deep-water reservoirs and backwaters. The Littoral Subsystem is represented by the shallower backwater or artificial impoundments to a depth of 2 m (7 ft) below low-water line and the shoreward boundary of Limnetic waters.

Water movement is typically very slow in all Lacustrine wetlands. Oxygen content, flora, and fauna are variable to class and subclass. Classes and subclasses on the lower Colorado River are the same as listed in the Riverine System.

Palustrine System

The Palustrine System includes all wetlands dominated by trees, shrubs, and persistent emergents. Palustrine wetlands are bounded by upland habitats or by nonpersistent wetlands. Palustrine wetlands may be situated shoreward of lakes or river channels, on river floodplains, in isolated catchments, or on slopes. They may also occur as islands in lakes or rivers. Palustrine wetlands are more popularly known as riparian habitats.

Emergent vegetation adjacent to rivers and lakes is sometimes separated from the river or lake itself and is therefore treated under the Palustrine System. Classes and subclasses are the same as those listed under Riverine System with the addition of Palustrine Persistent Emergent Wetlands, Swamp-scrub, and Broad-leaved Deciduous Forest Wetland. The latter two subclasses are further classified in the following sections.

A.2 METHODS FOR CLASSIFICATION OF PALUSTRINE (RIPARIAN) HABITATS ON THE LOWER COLORADO RIVER

The purpose of this and the following sections is to describe attributes of riparian plant communities that have been found to be useful in evaluating habitat values for vertebrate wildlife on the lower Colorado River. We describe a method for measuring these attributes and how these measurements may be useful in predicting presence or absence of wildlife species and their abundance. This presentation is not the only possible classification methodology. This section is not intended, therefore, to be an exhaustive review of all, or even a majority, of the methods available. For a more general review of classification of vegetation, the reader should consult references such as Kuchler (1967), Daubenmire (1968), Whittaker (1975), and Brown and Lowe (1974).

In classifying vegetation communities a two- or three-dimensional approach should be considered. In general, the physiognomy or structure of the vegetation represents two dimensions. For example, a given stand of vegetation varies in vertical and horizontal space. Variation in the vertical dimension, whether it is single or multilayered, is particularly useful in describing the stand. Similarly, the floristics, i.e., species composition of a stand, is often important in describing that stand. The structure and floristics can be quantified relatively quickly and easily and limits to a vegetation type can be then unambiguously defined.

The same characteristics used to quantitatively describe a stand of vegetation can be used in developing predictive capabilities relative to the resident wildlife. It is our purpose here to describe field methods, which are reasonably fast and accurate, that can be used for quantitatively classifying vegetation and quantifying wildlife associations with various attributes of vegetation communities.

Basic Variables

Foliage density and the species composition are referred to as simple basic variables because they are usually variables that are measured in the field.

Foliage density and structure. Foliage density refers to the amount of green foliage present or to the amount of leaf-bearing stems and leaves per unit area. Usually foliage density is measured at various vertical increments that reflect components of understory, midstory, and canopy (Figures A-2 and A-3). Foliage density measurements taken in summer may be useful in describing the foliage density in winter, in terms of the relative amounts of leaf-bearing stems and leaves present; thus, negating the need for measurements in winter. This procedure is most valid in areas where trees or annuals predominate (Anderson and Ohmart 1982b). Data collected to determine foliage density also can be used to determine structural characteristics in both vertical and horizontal space.

Species composition. The species composition of an area can be determined by counting individuals of each tree/shrub species present. This is not as simple as it sounds; size classes must be considered. Even then, two trees of the same height and species can be quite different. Tree health or tree density can affect general structure.

Fruit production. In stands of vegetation that produce fruit, espe-

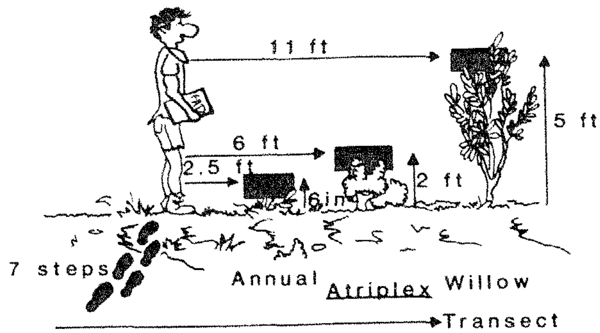


Figure A-2. Selection of vegetation for foliage density measurements. From Anderson and Ohmart (1984b).

cially fruits that are sought by wildlife, it may be useful to obtain some idea of the total fruit produced. This is important when the correlation between number of trees present and fruit production is rather poor. For example, mistletoe along the lower Colorado River parasitizes honey mesquite more frequently than other tree species (Figure A-4). However, the proportion of trees parasitized varies widely from stand to stand. Estimates can be obtained of the number of mistletoe clumps in a given stand by counting trees parasitized in sample plots and calculating an average of clumps per tree. Similarly, pod production by individual mesquite trees varies widely between stands, resulting in a poor correlation between number of trees present and production of pods.

Transect Data Collection

Field methods for quantifying vegetation are the same as those developed and discussed in detail by Anderson et al. (1983) and Anderson and Ohmart (1984c, 1986c). We describe these techniques here, but refer the reader to these reports for justification and background data.

Transects were established through large stands of relatively homogeneous vegetation. These transects were used

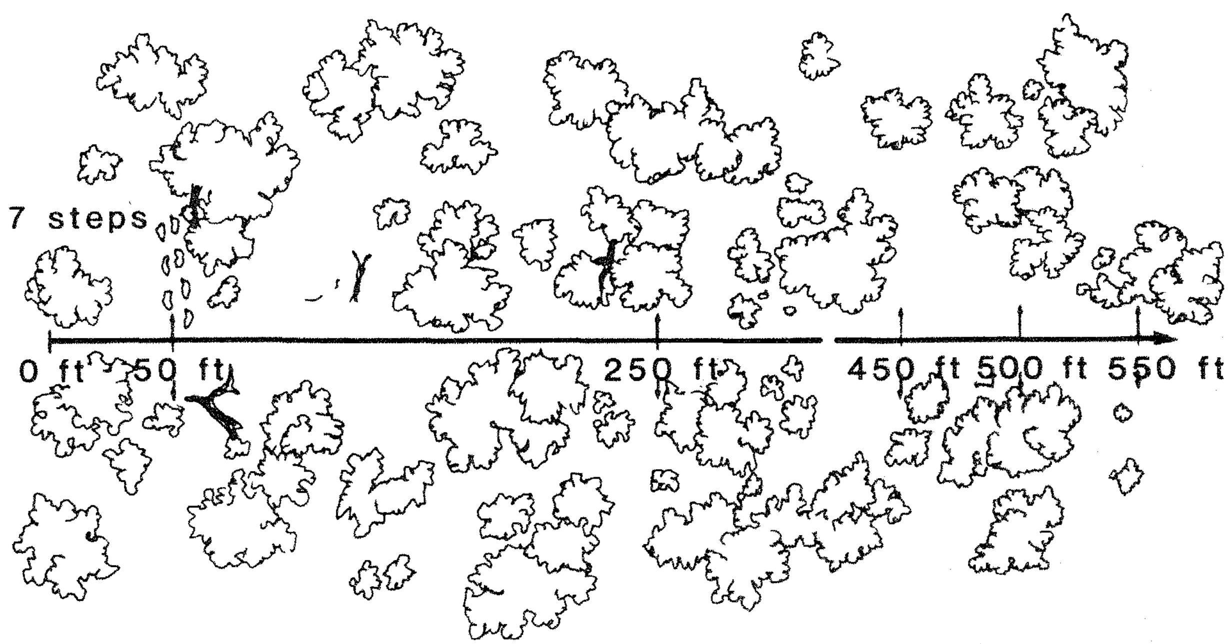


Figure A-3. Sampling points for foliage density measurements. From Anderson and Ohmart (1984b).

Figure A-4. Mistletoe-infested honey mesquites provide important food sources for frugivorous bird species, especially Phainopepla. Photo is from near Ehrenberg, AZ by W.C. Hunter.

to sample vegetation structure, plant composition, and to census birds and other wildlife. Transects were usually 760 m (2,500 ft) in length but ranged from 456 to 1,672 m (1,500 to 5,500 ft).

Vegetation density and vertical and horizontal diversity were sampled along each transect using the board technique of MacArthur and MacArthur (1961). Foliage density was measured at intervals of 61 m (200 ft) along transects (lateral distance from transect to where foliage covers at least half of a 21-X-29-cm [8.5-X-11-in] board) at vertical heights of 0.15 m (0.5 ft), 0.6 m (2 ft), and every subsequent 1.5 m (5 ft) to the top of the canopy. Foliage height diversity (FHD) and horizontal patchiness (HDI) values were calculated from the above data as described below.

Tree and shrub counts were conducted to determine plant species composition. Young trees that were shrub size (<3 m [10 ft]) were still counted as trees. Certain shrubs and patches of young trees in dense clumps were counted by measuring foliage diameter and foliage height of each clump and then converted to counts of individuals. Thus, calculating the minimum number of shrubs in an area was possible by estimating the percent ground cover in each 15-X-150-m (50-X-500-ft) strip of dense shrub cover. Total numbers of trees and shrubs of each species within a 15-m (50-ft) strip on each side of the transect were recorded. Tree and shrub counts were converted into density of all trees and shrubs per ha (acres) of each species for each transect.

Transect Data Analysis

Vegetation data were analyzed by transect and by grouping transects (stands) into habitats as defined below. Analysis on a habitat scale was done by averaging the values from each transect for all vegetation components. These data provide a baseline from which comparisons can be made between similar stands of vegetation on other river systems in the Southwest.

Foliage density at each height is based on the amount of distance from the observer in which foliage will cover half a board. The farther the vegetation from the observer the less dense vegetation at that height will be. Alternatively, the closer the vegetation is to the observer the more dense vegetation at that height will be. Because of mathematical problems associated with estimating distances <0.3 m (<1 ft) away from the observer, all distances >0 but <0.3 m (<1 ft) are recorded as 0.3 m (1 ft). All distances over 0.3 m (1 ft) are measured to the nearest 0.3 m (1 ft). The following formula is used to convert the measurement to surface area of vegetation per cubic unit of space (i.e., foliage density):

$$K = \frac{\log_e 2}{D} = \frac{0.693}{D}$$

where K = foliage density and D = measured distance.

Transects were divided into plots each 152 m (500 ft) long and 122 m (400 ft) wide. A transect 762 m (2,500 ft) long would have 10 plots (Figure A-5). Data from three points

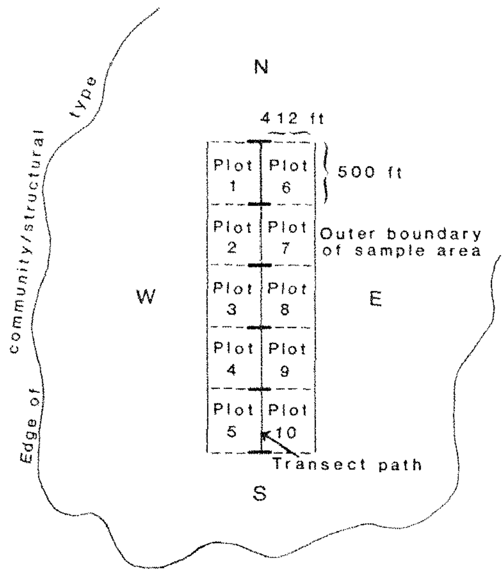


Figure A-5. Typical transect showing individual plots and outer boundaries. From Anderson and Ohmart (1984b).

(61 m [200 ft] apart) in each subplot are taken to determine the average foliage density of each height within the plot. No more than three points are necessary to arrive at this value for each plot (Anderson and Ohmart 1986c). For example, foliage density at a height level of 1.5 m (5 ft) in one plot, for which distances were 3, 4.5, and 0.6 m (9, 15, and 2 ft, respectively) would be calculated as follows:

$$(0.693/3+0.693/4.5+0.693/0.6)/3=0.513$$

For the 762-m (2,500-ft) transect, the average of the 10 plots is used to determine the foliage density at that height.

The vegetation structure of a transect is based on the foliage density at each layer divided by the total foliage density. Three layers are defined which correspond to the herbal and shrub understory (0-1.5 m [0-5 ft]), the midstory (1.5-4.6 m [5-15 ft]), and the canopy (>4.6 m [>15 ft]). These definitions are arbitrary in that the purpose was to assess vegetation structure in terms of development (i.e., succession) and use by wildlife; however, an investigator with different goals could easily develop "sublayers" such as upper midstory, lower canopy, and upper canopy if desired. A sample of vegetation measurements, as they were taken in the field, is given in Table A-1 with foliage density calculations. Although foliage density serves as the basis for vegetation type mapping of structure as described below, there are two other important indices to discuss, vertical diversity and horizontal diversity (or patchiness).

Foliage height (vertical) diversity is simply a way of determining the complexity of structure within any particular stand and can serve as a comparative measure among stands (Figure A-6). Foliage height diversity is calculated for each transect according to information theory (Shannon and Weaver 1949) as follows:

$$FHD = \sum_{i}^{n}(p_i)\ (\log_n p_i)$$

where p_i is the proportion of total foliage density contributed by the density at level i. (Sample calculations are shown in Table A-1).

A maximum FHD value is reached when each layer contains an equal proportion of foliage. FHD is calculated from foliage density values as given in the understory and midstory layers but the canopy layer here is divided into two sublayers (4.6-7.6 m and 7.6-18 m [16-25 ft and 25-60 ft]). Therefore, on the lower Colorado River four possible layers are used in calculating FHD. This breakdown is arbitrary but is consistent with Anderson and Ohmart (1984c, 1986c). Each transect is then compared to maximum possible diversity (which equals, in this case, 1.39; Table A-1). Percent of maximum diversity thus serves as the gauge to compare transects.

There is one caveat in interpreting FHD among transects while ignoring other parameters. A similar FHD value may be obtained from stands of vegetation that differ structurally. A transect with a well-developed understory but little midstory or canopy will have a similar value to a transect with a well-developed midstory but no understory nor canopy. Even though FHD is a convenient index to compare stands, it should not be used without knowledge of the structure of stands being compared.

Horizontal diversity is simply a measure of structure determining the regularity of vegetation distribution within a horizontal plane. An orchard with regularly spaced trees or a grassy field will have little or no variation in horizontal diversity. The more holes, gaps, and differences in growth form there are within a stand the more variation in horizontal diversity there will be. A stand exhibiting much variation in the horizontal plane is often referred to as being "patchy" (i.e., there are many different patches of vegetation within the stand; Figure A-7).

Horizontal diversity is the variance associated with the mean total foliage density. Variance or standard deviation squared (s^2) is defined as:

$$HDI = s^2 = \sum_{j=1}^{n} \frac{K_i^2 - (\Sigma K_i)^2/n}{n - 1}$$

Table A-1. Sample foliage density estimates used for calculating patchiness and foliage height diversity. Table from Anderson and Ohmart (1984c).

Plot	Foliage density (ft^2/ft^3) 0.5 ft (0.15 m)	2 ft (0.6 m)	5 ft (1.5 m)	10 ft (3.0 m)	15 ft (4.6 m)
1	0.16	0.20	0.29	0.10	0.01
2	0.12	0.15	0.23	0.06	--
3	0.08	0.09	0.27	0.09	0.01
4	0.28	0.15	0.09	0.01	0.00
5	0.19	0.22	0.09	0.02	0.00
6	0.18	0.34	0.29	0.10	0.02
7	0.07	0.31	0.31	0.03	0.01
8	0.08	0.18	0.31	0.02	--
9	0.15	0.16	0.32	0.03	--
10	0.23	0.15	0.13	0.01	--

	Patchiness index 0.5-2 ft (0.15-0.6 m)	5-10 ft (1.5-3.0 m)	15-20 ft (4.6-6.0 m)	≥25ft (≥7.5 m)	Total
Mean total density	0.35	0.28	0.00	--	
$PI(s^2)$	0.01	0.01	0.00	--	0.02

	Calculation of foliage height diversity 0.5-2 ft (0.15-0.6 m)	5-10 ft (1.5-3.0 m)	15-20 ft (4.6-6.0 m)	≥25 ft (≥7.5 m)	Total
Mean total density	0.35	0.28	0.00	0	0.63
Proportion (p_i)	0.55	0.44	0.01	0	
$\log_{10} p_i$	-0.26	-0.36	-2.20	0	
$p_i \log_{10} p_i$	-0.14	-0.16	-0.01	0	FHD = 0.31

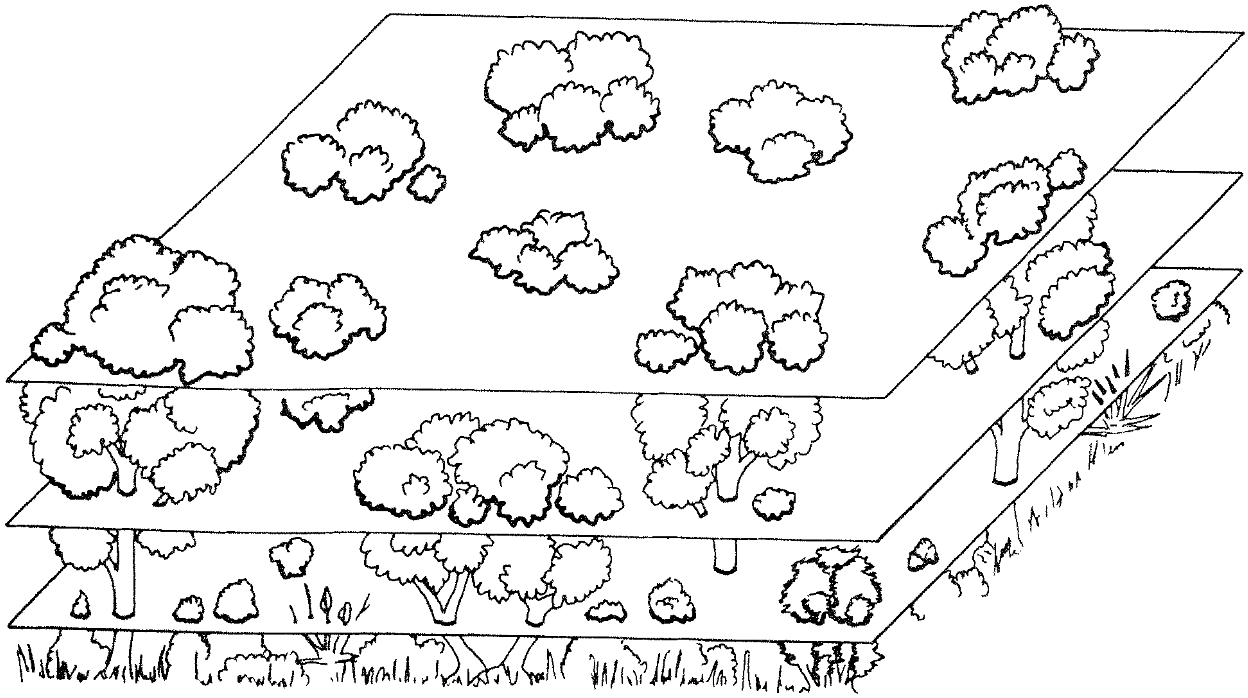
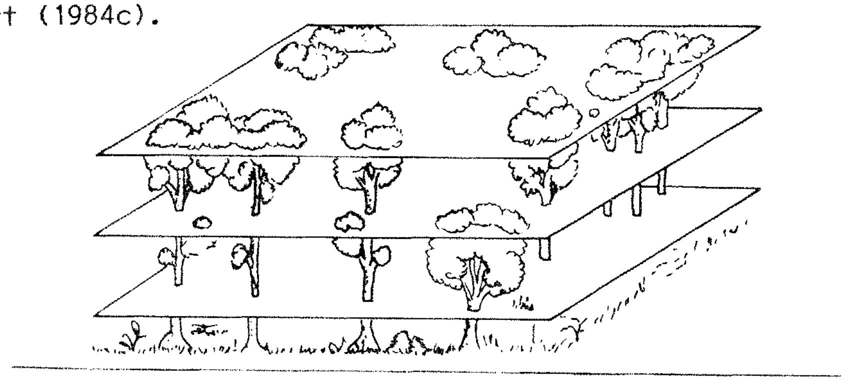


Figure A-6. Diagrammatic representation of foliage diversity in the vertical plane. The stand shown depicts an area of at least 10 ha (25 acres). From Anderson and Ohmart (1984c).



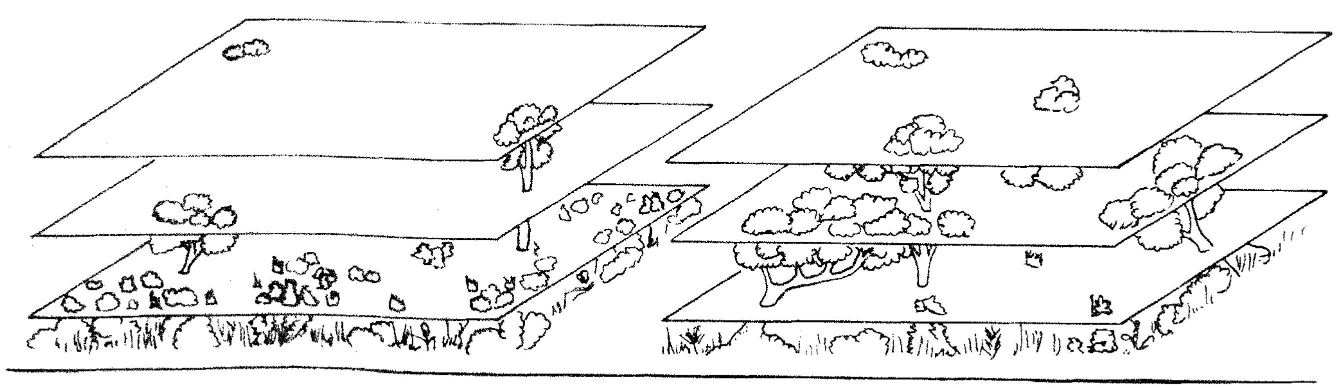


Figure A-7. Diagrammatic representation of foliage diversity (patchiness) in the horizontal plane at each of three vertical layers. The blocks represent patches of roughly 2 ha (5 acres). From Anderson and Ohmart (1984c).

where K_i = foliage density at the ith sample; $(\Sigma K_i)^2/n$ = the mean foliage density for the sample; n = sample size; and HDI = horizontal diversity index. This variance is calculated for each vertical layer. Total horizontal diversity is the sum of the variances for all layers. See Table A-1 for sample calculations.

The variance associated with the mean total density for each vertical layer across all plots can be used as a measure of horizontal patchiness. Since 0.00 and 0.69 represent the extremes of possible foliage density values, maximum horizontal diversity for a given layer is 0.238. Since we have already identified four layers for FHD, the maximum horizontal diversity for any stand is 0.952. This value is close to 1.0 so the sum of the variance for any stand represents the percentage of the maximum possible.

Another method for calculating FHD and patchiness might be to simply record the presence or absence of vegetation at various vertical positions. This could be done with a long pole and/or a rangefinder. More stops would have to be made, but FHD, relative density values, and patchiness estimates could be made on the basis of the proportion of total points at which foliage occurred. This method might be quicker, would reduce the amount of required calculations, and might be equally as accurate.

A.3 CLASSIFYING VEGETATION

Habitat Heterogeneity

Field techniques. As stated by Anderson and Ohmart (1986c), there is often a shortage of time, money, and personnel to accomplish a satisfactory type-mapping effort over a large area which has tremendous variation in composition and structure type--such as is found in riparian vegetation. A system must be relatively simple in identifying possible types, be compatible with field limitations, and be able to imply other plant descriptors (i.e., foliage density, FHD, and HDI). Also, the methodologies must be able to accomplish the goals set for the mapping effort, whether it to be to assess (i.e., health of the system), management practices or wildlife use.

The Brown and Lowe (1974) system is excellent for identifying biomes, formations, series, and plant associations. This system is hierarchical in nature, digital (and, thus, computer compatible), and allows simple identification of types from aerial photographs or from ground truthing. Another system the National Wetlands Inventory system (Cowardin et al. 1979), is most suited for identifying physical factors (e.g., soil, stream condition, slope) and is also widely used and is national in scope. These systems are compatible with each other and are open-ended in describing riparian habitats.

Structure types is not specifically included in either of the above systems, but would be included as a "phase" in either system. The Anderson and Ohmart (1986c) system allows for quantification and easy identification of six basic structure types in the field. The number of structure types is based on the relative importance of understory, midstory, and canopy (Figure A-8). These are based on foliage measurements in each layer (Figure A-9). Anderson and Ohmart (1986c) and Anderson et al. (1983) provided a detailed analysis of vegetation characteristics (tree counts, foliage density, FHD, and HDI) for each type in each identified plant community (=association).

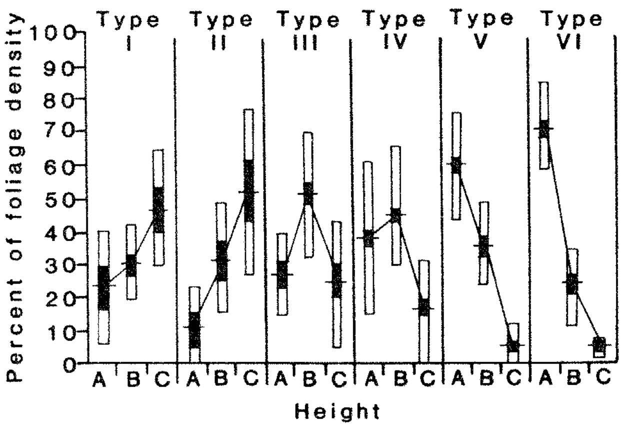


Figure A-8. Proportional distribution of the vegetation in three vertical layers among subplots within various stands of vegetation which overall were classified as belonging to one vertical structural type (I-VI). Horizontal lines represent mean values; large rectangles represent one standard deviation; small rectangles represent two standard errors. A = 0.0-0.6 m (0-2 ft); B = 0.6-4.5 m (2-15 ft); and C = ≥4.5 m (≥15 ft). From Anderson and Ohmart (1984c).

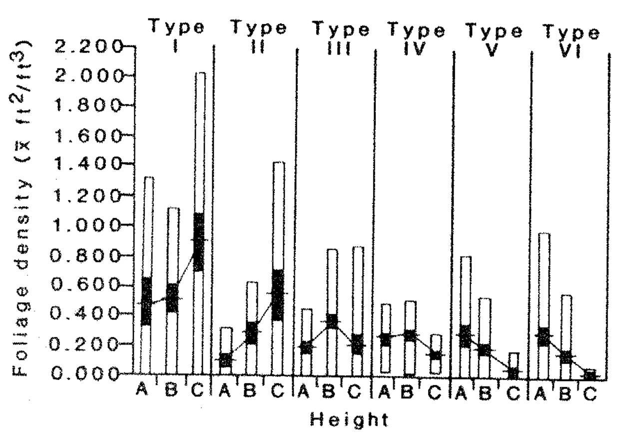


Figure A-9. Variation in foliage density between plots within all structural types at each of three vertical levels. Note that the proportional distribution leads to clear differentiation of the vegetation types, but that foliage density does not. Symbols and abbreviations as in Figure A-8. From Anderson and Ohmart (1984c).

The concept of structure typing is not difficult to understand if an area is envisioned as progressing from bare soil to supporting a mature cottonwood forest (Figure A-10). Type VI is the beginning community of regenerated vegetation. As the stand develops it passes through types V, IV, and then III until it becomes type I which is the mature community. In type VI the vast majority of foliage is in the understory. Type I, at the other extreme, has well-developed understory, midstory, and canopy layers; such habitats also tend to be very high in FHD and HDI (Anderson et al. 1983). As the stand continues to mature and a closed canopy develops, the understory tends to be shaded out, and the stands becomes type II. As the mature cottonwood or willow trees die and the canopy opens, the midstory develops with newly regenerated cottonwood or willow or other plant species (saltcedar and/or mesquite). Eventually, given no extrinsic factors (i.e., clearing, flooding, fire), the stand will undergo succession into a disclimax stand dominated by mesquite or other plant species. Presently, mesquite and saltcedar rarely develop beyond type III in the Southwest. Typically, the lower the structure type the more xeric, saline, or otherwise unfavorable the site is.

Other information can be quickly generated such as relative age of the stand. On the lower Colorado River we defined four age classes. Age class 1 represented a recently regenerated stand, 2 a young stand, 3 a mature stand, and 4 a stand tending toward decadence. These age classes are important to assess regeneration potential and possible future succession for each stand, given no dramatic extrinsic events.

Identification of structure types, age class, and dominant plant species can be facilitated by previous

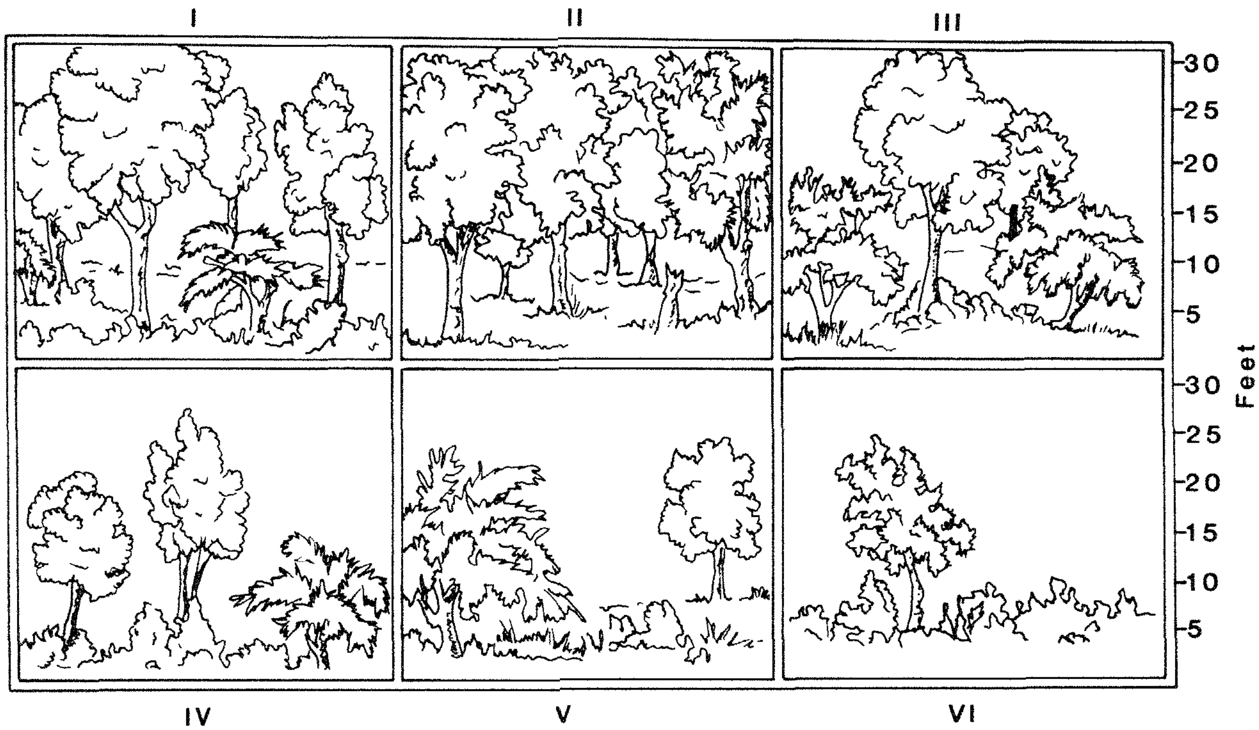


Figure A-10. Examples of vertical configurations for the vegetation structural types defined in Figure A-8 in the lower Colorado River Valley. From Anderson and Ohmart (1984c).

experience on other river systems or in-depth familiarity with the system under study. Type mapping an entire system can be done from aerial photography or from high vantage points adjacent to the river. Both techniques were used on the lower Colorado River during our study. Besides identifying habitats (=composition/structure type), it is also necessary to delineate areal extent and borders between different habitats.

The Anderson and Ohmart (1986c) system is sensitive to the area covered by each stand. This system becomes more suitable as stand size approaches 10 ha (25 acres). Smaller stands can be typed, but they do not mean much in terms of assessing the health of riparian vegetation or use by wildlife. Cloudiness begins to appear at a scale of about 20 ha (50 acres), and all predictability is lost at the scale of 2 ha (5 acres; Rosenberg 1980; Wiens and Rotenberry 1981a,b; Engel-Wilson 1982). In addition, the amount of time required to delineate stands of <10 ha (<25 acres) reduces the efficiency of the technique with no obvious benefit. As an aside, if the techniques are applied to very small riparian systems, where definable habitats rarely exceed 2 ha (5 acres), then preliminary data collection needs to be scaled down accordingly. In large riverine systems, it is simply impractical to type map stands <10 ha (25 acres) in size, although some very isolated and important stands may still be delineated.

Much of the field type mapping must rely on the training and experience of the observer, with ground truthing conducted to verify impressions. Mistakes will be made, but most errors are minor. A recent field test on the lower Colorado River by observers new to the system, after indoctrination, revealed about a 6% error on the total polygons delineated. About 50% of these errors involved misidentification of species composition in mixed saltcedar-mesquite (screwbean vs. honey) stands, 30% involved mistaking emergent and terrestrial riparian habitats from one another, and 20% involved mistaking one structure type for one immediately above or below it (i.e., calling a stand type IV when it is actually type III; Younker and Andersen 1986). Decisions to incorporate two or more small (<4 ha [<10 acres]) adjacent stands into one larger one may result in some error, but a general rule is that the larger the stand the more accurate the maps will be for future revisions and present use. Problems with the system and data application are discussed in greater detail below.

If the goal of a field project is to determine habitat associations for a wildlife group, such as birds, over a relatively large area (e.g., 40,000 ha [100,000 acres]), the area must be sampled sufficiently so that all habitats are represented by at least one sample plot (transected area), and replication is desirable. If sampling is done randomly, the number of transects per habitat will be proportional to the abundance of that habitat in the study area. All transects should be about the same length and should be within a relatively homogeneous stand. At this point, some arbitrary decisions may have to be made because of the ambiguity associated with the term "relatively homogeneous." A field biologist relatively familiar with an area will generally know how to define habitat types (Table A-2).

Including several transects in one habitat can increase within-habitat variation. The advantage of using the habitat concept is that habitats can be mapped, data are less cumbersome to deal with, and communication about habitats is easier than communication about transects. Furthermore, management is usually done with habitat as a concept. However, if microhabitat variation is extensive, use of the habitat concept should occur only after one is thoroughly familiar with the variation that will be concealed and the limitation this variability will place on subsequent data analyses.

<u>Foliage density.</u> In separating transects into structural types it would be wise to have the various structural types statistically different ($P<0.05$) from each other for at least one of the recognized vertical layers. Data from Anderson and Ohmart (1984a) and Anderson et al. (1983) are shown for foliage density in Figure A-9 and the proportion of foliage in each of three vertical layers is shown in Figure A-8. These figures illustrate the range of variation found among transects falling into each category; they also show the mean and two standard errors of the mean for each type. Note that when using foliage density measures, types V and VI differed little from each other, but when the proportion of the total foliage found in each of three layers is considered type VI had a significantly greater proportion of its total foliage in the lower layer and significantly less in the middle layer (Figure A-8). Transects can be distinguished from each other and grouped statistically into structure types by using cluster analysis (Figure A-11).

<u>Heterogeneity in tree counts.</u> The mean number of trees of a particular species can also vary considerably

Table A-2. User's guide to classifying vegetation by dominant tree or shrub species present. This key can be used to classify about 95% of the riparian vegetation found along the lower Colorado River. By applying the same general principles used to construct the key and a little imagination, rare vegetation types can also be classified. Table from Anderson and Ohmart (1984c).

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1. A. Stand in which virtually 100% of the trees present are of one species or virtually 100% arrowweed....................................Go to 2
   B. Trees within stand of clearly mixed species. The different species may occur as mixed individuals or as small clumps..................Go to 3

2. A. Stand in which trees are composed of nearly 100% of some species (may be occasional, widely scattered individuals of one or more species). Many large stands have arrowweed in patches encompassing 2 ha (5 ac) or more. Honey mesquite stands in addition to, or instead of, arrowweed may have quail bush, four-winged salt bush (*Atriplex canescens*), wolfberry, or inkweed..............Saltcedar I-IV or Honey Mesquite III-IV
   B. Stand composed of nearly 100% arrowweed, may be an occasional tree or widely scattered clump of some other shrub...................Arrowweed

3. A. Stand of vegetation is structural type I and trees are primarily saltcedar, cottonwood, and/or willow with an occasional widely scattered screwbean or honey mesquite tree or clumps of trees. Arrowweed or some other shrub may occur in relatively widely scattered clumps............ ....Saltcedar-Cottonwood/willow Mix
   B. Vegetation not structural type I................................Go to 4

4. A. Stand of vegetation is structural type II or III................Go to 5
   B. Stand not structural type II or III.............................Go to 6

5. A. Stand in which trees are saltcedar with large numbers of cottonwood and/or willow present; may be widely scattered individuals or clumps of screwbean or honey mesquite............Saltcedar-Cottonwood/willow Mix
   B. Stand in which trees are mainly saltcedar and screwbean mesquite; may be an occasional, widely scattered clump or individual cottonwood and/or willow or honey mesquite........Saltcedar-Screwbean Mesquite Mix

6. A. Stand of vegetation is structural type IV......................Go to 7
   B. Stand not structural type IV...................................Go to 8

7. A. Stand composed mainly of saltcedar but with significant numbers of cottonwood and/or willow present; may be widely scattered individuals or clumps of screwbean or honey mesquite. Shrubs, mainly arrowweed, abundant and occurring in moderate to relatively large patches sometimes encompassing 2 ha (5 ac) more.................................. ....Saltcedar-Cottonwood/willow Mix
   B. Stand much as above but with screwbean mesquite or honey mesquite instead of cottonwood and/or willow.................................... ....Saltcedar-Screwbean Mesquite Mix or Saltcedar-Honey Mesquite Mix

(Continued)

Table A-2. (Concluded)

8. A. Stand of vegetation is structural type V or VI..................Go to 9
   B. Stand not structural type V or VI...............................Go to 3
9. A. Stand composed mainly of saltcedar, but with significant numbers of cottonwood and/or willow occurring as scattered individuals or clumps. Arrowweed is usually abundant (occasionally some other shrub species such as quail bush also present) and occurring in patches encompassing several hectares (acres)................Saltcedar-Cottonwood/willow Mix
   B. Stand composed primarily of saltcedar but with significant numbers of individuals or clumps of screwbean or honey mesquite. May be widely scattered individuals or clumps of screwbean or honey mesquite. Arrowweed present as in 9.A...
.......Saltcedar-Screwbean Mesquite Mix or Saltcedar-Honey mesquite Mix

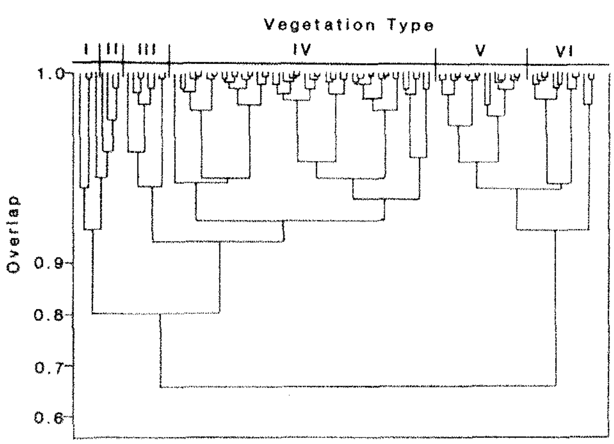

Figure A-11. Dendrogram showing relationships between all transects based on overlap, foliage density, and structure. From Anderson et al. (1977).

among patches. For example, the mean number of saltcedar per saltcedar thicket with patches of shrubs was 163 trees with a very large standard deviation (105; Table A-3). This variation is to be expected in patchy habitats. It will be noted, however, that habitats classified as honey mesquite woodland had very few tree species present other than honey mesquite; saltcedar thickets had only one species present other than saltcedar (Table A-3). Thus, while saltcedar is virtually the only tree species present in saltcedar habitats, the trees within such habitats may be tall and relatively homogeneously distributed (type I) or scrubby with patches of shrubs intermingled among the saltcedar.

Within-habitat variation can also be caused by highly localized edaphic features. For example, the soil moisture level in an old oxbow that is intersected by the transect, may allow a few individuals of a tree species not found to occur elsewhere.

The distribution of soil types within a floodplain is typically heterogeneous. Local heterogeneity in soil layering and structure can cause heterogeneity in plant structure. A highly localized dense clay soil type could cause a very local concentration of soil electrolytes. Vegetation growing in such soil often attains less stature and biomass (Anderson and Ohmart 1982a; Anderson et al., unpubl. MS), and, therefore, vertical differentiation is simpler than that of adjacent vegetation. Such variation may be so frequent that it is not feasible or desirable to delineate it.

Table A-3. Average number of trees (±1 SD) per subplot in each of 23 recognized riparian habitat types along the lower Colorado River. N refers to the number of subplots. SC = saltcedar, C = cottonwood, W = willow, SM = screwbean mesquite, HM = honey mesquite. From Anderson and Ohmart (1984c).

		Number of trees per 150-X-15-m (492-X-49-ft) subplots										Percent of subplots with no trees of dominant species
		SC		C		W		SM		HM		
Vegetation type	N	x̄	SD	x̄	SD	x̄	SD	x̄	SD	x̄	SD	
Saltcedar												
I	18	95	20	0	0	0	0	0	0	2	20	0
II	8	47	19	0	0	0	0	0	0	0	0	0
III	28	74	25	0	0	0	0	7	13	0	0	0
IV	32	163	105	0	0	0	0	0	0	0	0	0
V	109	133	146	0	0	0	0	1	3	0	0	1
VI	20	31	50	0	0	0	0	0	0	0	0	0
Saltcedar-cottonwood/willow												
I	18	52	13	59	27	87	23	0	0	0	0	0-0
II	10	129	46	38	22	49	34	0	0	0	0	0-0
III	62	130	147	19	44	54	66	13	23	6	7	0-6
IV	52	38	53	0	0	29	17	7	15	0	0	3-8
V	30	44	49	0	0	17	21	0	0	0	0	0-0
VI	22	19	32	1	1	1	26	0	0	0	0	0-50
Saltcedar-screwbean mesquite												
II	10	63	24	2	4	1	1	96	17	0	0	0-0
III	40	49	43	0	0	0	0	18	15	0	0	0-8
IV	78	60	58	0	0	4	25	39	31	0	0	1-6
V	84	45	39	0	0	0	0	44	62	0	0	0-8
VI	18	45	55	0	0	0	0	6	6	0	0	0-22
Saltcedar-honey mesquite												
IV	38	41	53	0	0	0	0	0	0	35	68	2-6
Honey mesquite												
III	24	0	0	0	0	0	0	<1[a]		93	50	0
IV	122	0	0	0	0	0	0	0	0	31	42	1
V	56	0	0	0	0	0	0	0	0	12	7	2
VI	52	0	0	0	0	0	0	<1[a]		9	7	2

[a]Standard deviation not calculated where x̄ <1.

Another source of variation includes widely distributed individual trees of formerly more widely distributed species. For example, in our study area cottonwood and willow trees, often occurring as widely scattered individuals or as small clumps (20 X 20 m [66 X 66 ft]) of trees, are relicts of a gradually disappearing habitat (Ohmart et al. 1977).

Fire, another cause of within-stand heterogeneity, has affected nearly every stand of vegetation along the lower Colorado River. When a stand is burned not all parts of it burn with equal intensity, at the same frequency, or redevelop at precisely the same rate. Thus, considerable heterogeneity can be found within any fundamentally homogeneous stand.

Some delineation of plant species heterogeneity may be important for understanding the distribution of vegetation or wildlife, but complete delineation could require more time and money than is available. Availability of funding and consideration of the desired scale are factors that must be considered when deciding how much edaphic variation should be delimited. A classification at a smaller scale will result in proliferation of recognizable vegetation types.

A.4 ANALYZING HETEROGENEITY AMONG HABITATS

Although many of the differences between two habitats may be obvious to the observer (a patchy saltcedar scrub thicket is obviously different in many ways from a cottonwood-willow gallery forest), it is often necessary to quantify these differences. Although one may be able to adequately describe the differences between two habitats, such a description may require several pages and cannot be used in statistical treatments. Therefore, differences must be expressed quantitatively. Among the community attributes measured, several may be intercorrelated; i.e., as the values for one increase the values for another also increase (or decrease). Colinearity generally precludes determining the extent to which either variable is associated with wildlife. In such situations it is possible for the data to show that a species or group of species are significantly associated with both variables. In reality, one of the variables may be attracting the species while the other one is of no value.

Only carefully designed experiments will delineate which attributes among the constellation of factors are really attracting wildlife. Principal components analysis (PCA) is a statistical tool that combines intercorrelated variables into new derived variables. The derived variables can usually be interpreted and can be treated as independent variables in subsequent analyses. Each habitat receives a score from roughly -3 to +3 on each derived variable. PCA of the lower Colorado River riparian vegetation yielded four derived variables (Table A-4). For example, the first included foliage density and diversity measures above the lowest layer and FHD. Wildlife associated with such a derived variable is most abundant in habitats with dense foliage that is horizontally and vertically diverse. The second derived variable, as a second example, was bipolar, i.e., the number of honey mesquite per unit area was positively associated with this component, and the number of saltcedar was negatively associated. Species positively associated with this derived variable were associated with honey mesquite but negatively with saltcedar.

Table A-4. Loadings of 16 vegetation variables on the VARIMAX rotated axes for each of 4 principal components. Data are from 23 riparian habitats occurring along the lower Colorado River. The explained variance for each variable is at the right and the percent of the total variance for all variables explained by each principal component is given at the bottom. Variables contributing ≥0.05 to a principal component are underlined. From Anderson and Ohmart (1984c).

Variables	Principal component I	II	III	IV	Percent variance explained
Patchiness 0.0-0.6 m	0.15	-0.05	<u>0.85</u>	0.05	74.8
Patchiness 0.6-4.5 m	<u>0.70</u>	0.09	0.34	0.27	68.7
Patchiness ≥4.5 m	<u>0.92</u>	-0.12	-0.13	-0.12	89.2
Patchiness sum	<u>0.89</u>	0.07	0.22	-0.09	85.4
Foliage density 0.0-0.6 m	0.03	0.08	<u>0.90</u>	-0.13	83.4
Foliage density 0.6-4.5 m	<u>0.89</u>	-0.08	0.16	0.03	82.5
Foliage density ≥4.5 m	<u>0.84</u>	-0.22	-0.20	-0.16	82.0
Foliage density sum	<u>0.88</u>	-0.09	0.06	-0.25	84.9
Foliage height diversity	<u>0.71</u>	-0.25	<u>-0.51</u>	0.02	82.7
Shrubs	-0.26	<u>0.67</u>	-0.01	0.19	55.2
Honey mesquite	0.05	<u>0.90</u>	-0.09	-0.04	82.2
Mistletoe	0.23	<u>0.85</u>	0.08	0.12	70.3
Saltcedar	0.16	<u>-0.75</u>	-0.11	0.32	70.3
Screwbean mesquite	0.12	-0.18	-0.38	<u>0.59</u>	53.9
Cottonwood-willow	0.31	-0.06	-0.09	<u>-0.71</u>	61.2
Proportion of trees that are saltcedar	-0.16	<u>-0.81</u>	-0.11	0.09	70.2
Percent of total variance explained	35.0	20.9	12.8	7.0	75.7

PCA can be used to compress a large and complex set of measurements (vegetation community attributes) into a small set of derived variables that can be used as independent variables. Associations between wildlife and the attributes of the habitats can be determined by using the wildlife populations associated with various habitats in conjunction with the score of that habitat for each of the derived variables. Techniques such as analysis of variance, simple linear correlation, and multiple regression are appropriate for quantifying the extent of such associations.

In summary, cluster analyses can be used to group transects with similar vertical configurations. These clusters can be further subdivided according to the numerically dominant vegetation present. By recognizing relatively few vertical configurations (stress similarities rather than differences), for example six, and relatively few subdivisions by dominant vegetation (again, six), one can define up to 36 different habitats all of which differ from each other by vertical configuration, dominant vegetation, or both. Thus, when looking at a stand of vegetation, the manager needs to answer only two questions to classify the stand: (1) What is the vertical configuration of the vegetation, i.e., it is four-layered, three-layered, etc., and (2) what plant species appear to be numerically dominant in the stand? Thus, in a short period of time with a classification scheme such as the one described here, the manager can acquire enough general information about the stand to describe it in detail.

A.5 DETERMINING WILDLIFE-HABITAT ASSOCIATIONS

Wildlife Community Attributes

Tree/shrub counts of individuals were particularly useful in predicting the presence and densities of many rodent and bird species (e.g., Anderson and Ohmart 1984b, 1985b; Rice et al. 1983, 1984). We found that patchiness and FHD have useful predictive value, but they are not as good a predictor as tree/shrub counts (Anderson and Ohmart 1984b, 1985b; Rice et al. 1983, 1984). Mistletoe counts were associated with the presence of frugivorous birds (Anderson and Ohmart 1978).

The habitat breadth of each species can be used to classify them as habitat specialists (narrow habitat breadths) or habitat generalists. For example, data for Bell's vireo, summer tanager, and yellow-billed cuckoo identify these species as habitat specialists and that cottonwood-willow woodlands are their "preferred" habitats (Meents et al. 1984). Generally, there are relationships between each species and vegetation attributes, but the manager may choose to emphasize the relationship of one or a few species. Another example, the Yuma clapper rail, an endangered species, is of great interest and would be involved in any analysis involving habitat impacts (Anderson and Ohmart 1985a).

Deer use of habitats was quantified by identifying deer-use areas (foraging, resting, fawning, etc.) and analyzing the vegetation in four subplots within plots 30 X 30 m (98 X 98 ft). Vegetation measurements and tree counts were taken within these subplots in the manner described above. In addition, measurements were taken in a series of randomly selected plots. Attributes of the vegetation in the deer-use plots were then compared statistically with those in randomly selected control plots (Haywood et al. 1984).

Lizard use of a heterogeneous 30-ha (75-acre) area was determined by setting pit-trap arrays scattered within plots measuring 3 X 3 m (10 X 10 ft). Attributes of the vegetation were then determined by the methods described above. The nature of the substrate (sand, hardpan, etc.) was also noted. These plots were visited daily at the time of peak lizard activity, and the number of each species detected was recorded. The characteristics of the landscape could then be associated with the greatest numbers of detections of various lizard species (Anderson and Ohmart 1982b). Data obtained from bucket traps were used to corroborate or refute observational data.

Rodent association with various habitats was determined using multiple regression analysis where relative densities of each rodent species were the dependent variables and the vegetation factor scores for each habitat (determined from PCA) were the independent variables. Curvilinear relationships were also considered (Anderson and Ohmart 1984b).

Finally, the effect of clearing vegetation was determined by obtaining vegetation attributes of control and experimental areas (those to be cleared) before clearing. The effect of clearing, according to different patterns and amounts, was determined for each vegetation attribute separately (FHD, foliage density, etc.). Controls indicated the extent of change when no clearing was done. We also noted change in principal component factor scores for each of the affected habitats. Bird and rodent numbers were obtained before and after clearing in experimental and control areas to assess the effect on wildlife in various habitats (Anderson and Ohmart 1986a).

All of the vegetation variables given above may be important to at least some species of wildlife. Considerable seasonal variation in habitat selection may occur within a group, i.e., birds (Anderson and Ohmart 1984b; Rice et al. 1981). In addition, rodents used the vegetation differently in any given season than the majority of bird species. There is no *a priori* means of selecting a single attribute, or even a few attributes, that will be adequate for predicting the occurrence of all wildlife in a habitat. Use of any or all of the above data applications requires that a manager have well-defined questions and goals, while also having a clear understanding of limitations in using one or a few indices in defining an entire system.

APPENDIX B. Distribution, seasonal occurrence, abundance, and habitat use summary for birds on the lower Colorado River. Seasonal preference: Wi = winter, Sp = spring, Su = summer, LS = Late summer, Fa = fall. General abundance: C = common, FC = fairly common, U = uncommon, R = rare, Acc = accidental. Change from historical status: Inc. = increase, Dec. = decrease. Primary habitats: O = open water, M = marsh, R = riparian, A = agriculture, U = urban-suburban, D = desert, X = primary choice or choices, and + secondary choice or choices, * = breeding.

	Seasonal presence					General abundance					Change from historical status		Primary habitats					
Species	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Red-throated loon (_Gavia stellata_)	X								X		X		X					
Pacific loon (_Gavia pacifica_)	X	X			X				X		X		X					
Common loon (_Gavia immer_)	X	X			X			X			X		X					
Least grebe* (_Tachybaptus dominicus_)			X							X			X	X				
Pied-billed grebe* (_Podilymbus podiceps_)	X	X	X	X	X	X							X	X				
Horned grebe (_Podiceps auritus_)	X	X			X				X		X		X					
Red-necked grebe (_Podiceps grisegena_)	X									X			X					
Eared grebe (_Podiceps nigricollis_)	X	X	+	+	X	X		+			X		X					
Western grebe* (_Aechmophorus occidentalis_)	X	X	X	X	X		X				X		X	X				
Clark's grebe* (_Aechmophorus clarkii_)	X	X	X	X	X		X				X		X	X				

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Laysan albatross (<u>Diomedea</u> <u>immutabilis</u>)			X							X								
Least storm-petrel (<u>Oceanodroma</u> <u>microsoma</u>)				X						X			X					
Blue-footed booby (<u>Sula</u> <u>nebouxii</u>)	X			X	X				X				X					
Brown booby (<u>Sula</u> <u>leucogaster</u>)	X	X	X	X	X				X				X					
American white pelican (<u>Pelecanus</u> <u>erythrorhynchos</u>)	+	X	+	X	+			X	+				X					
Brown pelican (<u>Pelecanus</u> <u>occidentalis</u>)	X	X	X	X	X				X				X					
Double-crested cormorant* (<u>Phalacrocorax</u> <u>auritus</u>)	X	+	+	+	X	X	+				X		X	X	X			
Olivaceous cormorant (<u>Phalacrocorax</u> <u>olivaceous</u>)	X	X		X					X				X	X				
Magnificent frigatebird (<u>Fregata</u> <u>magnificens</u>)			X	X					X				X					
American bittern* (<u>Botaurus</u> <u>lentiginosus</u>)	X	X		X	X			X									X	
Least bittern* (<u>Ixobrychus</u> <u>exilis</u>)	+	X	X	X	+	X			+		X			X				
Great blue heron* (<u>Ardea</u> <u>herodias</u>)	X	X	X	X	X		X							X	X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Great egret* (<u>Casmerodius albus</u>)	X	X	X	X	X		X							X	X			
Snowy egret* (<u>Egretta thula</u>)	X	X	X	X	X		X							X	X			
Little blue heron (<u>Egretta caerulea</u>)			X	X						X				X				
Tricolored heron (<u>Egretta tricolor</u>)				X						X				X				
Reddish egret (<u>Egretta rufescens</u>)	X			X	X					X				X				
Cattle egret* (<u>Bubulcus ibis</u>)	X	X	X	X	X		X				X			X	X	X		
Green-backed heron* (<u>Butorides striatus</u>)	+	X	X	X	+		X	+						X	X			
Black-crowned night-heron* (<u>Nycticorax nycticorax</u>)	X	X	X	X	X		X							X	X			
Yellow-crowned night-heron (<u>Nycticorax violaceus</u>)		X								X				X				
White ibis (<u>Eudocimus albus</u>)		X								X				X				
White-faced ibis (<u>Plegadis chihi</u>)	+	X	X	X	+			X	+									
Roseate spoonbill (<u>Ajaia ajaja</u>)	X		X	X	X					X				X				

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Wood stork (_Mycteria americana_)			X	X					X			X		X		X		
Fulvous whistling-duck* (_Dendrocygna bicolor_)	X	X	X	X	X				X			X	X	X				
Tundra swan (_Cygnus columbianus_)	X				X				X				X	X				
Greater white-fronted goose (_Anser albrifons_)	+	+		X	X			X	+				X			X		
Snow goose (_Chen caerulescens_)	+	+			X		X	+					X			X		
Ross' goose (_Chen rossii_)	X				X			X			X		X			X		
Brant (_Branta bernicla_)	X									X			X			X		
Canada goose (_Branta canadensis_)	X				X		X				X		X	X		X		
Wood duck (_Aix sponsa_)	X				X				X				X	X				
Green-winged teal (_Anas crecca_)	X	X		X	X	X							X	X		X		
Mallard* (_Anas platyrhynchos_)	X	+	+	+	X	X		+					X	X				
Northern pintail (_Anas acuta_)	X	+		X	X	X	+						X	X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Blue-winged teal (*Anas discors*)	X	X	X	X	X				X				X	X				
Cinnamon teal* (*Anas cyanoptera*)	X	X	+	X		X	+						X	X		X		
Northern shoveler (*Anas clypeata*)	X	+	+	X	X			X	+				X	X				
Gadwall* (*Anas strepera*)	X	X	+	+	X		X		+				X	X				
Eurasian wigeon (*Anas penelope*)	X	X		X						X			X					
American wigeon (*Anas americana*)	X	+		+	+		X	X					X	X				
Canvasback (*Aythya valisineria*)	X	X			X			X					X					
Redhead* (*Aythya americana*)	X	X	+	+	X			X	+				X					
Ring-necked duck (*Aythya collaris*)	X	X			X			X					X					
Greater scaup (*Aythya marila*)	X	X							X				X					
Lesser scaup (*Aythya affinis*)	X	X	+		X			X	+				X					
Oldsquaw (*Clangula hyemalis*)	X								X				X					

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Black scoter (*Melanitta nigra*)	X									X			X					
Surf scoter (*Melanitta perspicillata*)	X				X				X				X					
White-winged scoter (*Melanitta fusca*)	X	X								X			X					
Common goldeneye (*Bucephala clangula*)	X	+			X		X	+			X		X					
Barrow's goldeneye (*Bucephala islandica*)	X	X			X				X		X		X					
Bufflehead (*Bucephala albeola*)	X	X			X			X			X		X					
Hooded merganser (*Lophodytes cucullatus*)	X				X				X				X					
Common merganser (*Mergus merganser*)	X	X	+	+	X			X	+				X					
Red-breasted merganser (*Mergus serrator*)	+	X	+	+	X			X	+				X					
Ruddy duck* (*Oxyura jamaicensis*)	X	X	+	X	X			X	+				X	X				
Turkey vulture* (*Carthartes aura*)	+	X	X	X	+		X	+							X	X		X
Osprey (*Pandion haliaetus*)	+	X	+	X	+			X	+				X	X				

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Black-shouldered kite (<u>Elanus caeruleus</u>)	X	X	X	X	X				X		X				X	X		
Mississippi kite (<u>Ictinia mississippiensis</u>)			X							X					X			
Bald eagle (<u>Haliaeetus leucocephalus</u>)	X				+			X	+				X	X				
Northern harrier (<u>Circus cyaneus</u>)	X	X	+	+	X	X		+						X	X	X		
Sharp-shinned hawk (<u>Accipiter striatus</u>)	X	X		X	X			X							X	X		
Cooper's hawk* (<u>Accipiter cooperii</u>)	X	X	+	X	X		X			+		+			X	X		
Northern goshawk (<u>Accipiter gentilis</u>)	X								X						X			
Common black-hawk (<u>Buteogallus anthracinus</u>)		X	X	X					X			X?			X			
Harris' hawk* (<u>Parabuteo unicinctus</u>)	X	X	X	X	X				X			X			X			
Red-shouldered hawk (<u>Buteo lineatus</u>)	X	X	X		X					X					X			
Broad-winged hawk (<u>Buteo platypterus</u>)		X								X					X			
Swainson's hawk (<u>Buteo swainsoni</u>)		X		X	X			X				X			X	X		X

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Zone-tailed hawk* (<u>Buteo albonotatus</u>)			X						X			X?			X			
Red-tailed hawk* (<u>Buteo jamaicensis</u>)	X	X	+	+	X		X	+							X	X		X
Ferruginous hawk (<u>Buteo regalis</u>)	X	X			X			X			X					X		
Rough-legged hawk (<u>Buteo lagopus</u>)	X								X							X		
Golden eagle (<u>Aquila chrysaetos</u>)	X	X	X	X	X				X							X		X
Crested caracara (<u>Polyborus plancus</u>)	X									X						X		
American kestrel* (<u>Falco sparverius</u>)	X	X	+	+	X	X		+							X	X		X
Merlin (<u>Falco columbarius</u>)	X	X			X				X						X	X		
Peregrine falcon* (<u>Falco peregrinus</u>)	X	X	X	X	X				X				X	X		X		X
Prairie falcon* (<u>Falco mexicanus</u>)	X	X	+	X	X			X	+							X		X
Ring-necked pheasant (<u>Phasianus colchicus</u>)	X	X	X	X	X				X		X				X	X		
Gambel's quail* (<u>Callipepla gambelii</u>)	X	X	X	X	X	X									X	X		X

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Black rail* (*Laterallus jamaicensis*)	X	X	X	X	X				X		X?			X				
Clapper rail* (*Rallus longirostris*)	+	X	X	X	+		X		+		X?			X				
Virginia rail* (*Rallus limicola*)	X	X	+	+	X	X	+							X				
Sora (*Porzana carolina*)	X	X	+	X	X	X			+					X				
Common moorhen* (*Gallinula chloropus*)	X	X	X	X	X		X						X	X				
American coot* (*Fulica americana*)	X	X	X	X	X	X							X	X				
Sandhill crane (*Grus canadensis*)	X				X		X						X	X		X		
Northern jacana (*Jacana spinosa*)			X							X				X				
Black-bellied plover (*Pluvialis squatarola*)		X		X	+			X	+					X	X			
Lesser golden-plover (*Pluvialis dominica*)				X	X				X					X	X			
Snowy plover (*Charadrius alexandrinus*)	+	X	+	X	+			X	+					X	X			
Semipalmated plover (*Charadrius semipalmatus*)		X		X	X			X						X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Killdeer* (*Charadrius vociferus*)	X	X	+	+	X	X	+							X		X		
Mountain plover (*Charadrius montanus*)	X	X			X			X			X					X		
Black-necked stilt* (*Himantopus mexicanus*)		X	+	X	+	X	+							X		X		
American avocet (*Recurvirostra americana*)	+	X	+	X	+	X			+					X		X		
Greater yellowlegs (*Tringa melanoleuca*)	+	X		X	+		X	+						X		X		
Lesser yellowlegs (*Tringa flavipes*)		+		X				X	+					X		X		
Solitary sandpiper (*Tringa solitaria*)		+		X				X	+					X		X		
Willet (*Catoptrophorus semipalmatus*)		X	+	X				X	+					X		X		
Spotted sandpiper (*Actitis macularia*)	X	X	+	X	X	X		+						X		X		
Upland sandpiper (*Bartramia longicauda*)				X						X						X		
Whimbrel (*Numenius phaeopus*)		X		X				X			X			X		X		
Long-billed curlew (*Numenius americanus*)		X	+	X														

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Marbled godwit (_Limosa fedoa_)	X	+	X	+		X	+							X		X		
Ruddy turnstone (_Arenaria interpres_)			X	X						X				X				
Black turnstone (_Arenaria melanocephala_)			X							X				X				
Red knot (_Calidris canutus_)				X	X					X				X				
Sanderling (_Calidris alba_)		X		X					X					X		X		
Semipalmated sandpiper (_Calidris pusilla_)				X						X				X				
Western sandpiper (_Calidris mauri_)	+	X		X			X		+					X		X		
Least sandpiper (_Calidris minutilla_)	X	X	+	X	X	X			+					X		X		
Baird's sandpiper (_Calidris bairdii_)				X	+			X	+					X		X		
Pectoral sandpiper (_Calidris melanotos_)				+	X			X	+					X		X		
Dunlin (_Calidris alpina_)	X				X				X					X		X		
Stilt sandpiper (_Calidris himantopus_)				X						X				X		X		

(Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Short-billed dowitcher (*Limnodromus griseus*)				X					X					X		X		
Long-billed dowitcher (*Limnodromus scolopaceus*)	+	X		X	+		X	+						X		X		
Common snipe (*Gallinago gallinago*)	X	X		+	X		X	+						X	X	X		
Wilson's phalarope (*Phalaropus tricolor*)		+	+	X			X	+					X			X		
Red-necked phalarope (*Phalaropus lobatus*)		+		X				X	+				X			X		
Red phalarope (*Phalaropus fulicarius*)					X				X				X					
Pomarine jaeger (*Stercocarius pomarinus*)				X						X			X					
Parasitic jaeger (*Stercocarius parasiticus*)				X	X				X		X		X					
Long-tailed jaeger (*Stercocarius longicaudus*)				X						X			X					
Laughing gull (*Larus atricilla*)		X	X	X						X			X	X		X		
Franklin's gull (*Larus pipixcan*)		X		+	X				X	+			X	X		X		
Bonaparte's gull (*Larus philadelphia*)	X	X		X	X				X				X	X				

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Heermann's gull (*Larus heermanni*)				X	X					X			X	X				
Mew gull (*Larus canus*)			X							X			X					
Ring-billed gull (*Larus delawarensis*)	X	+		+	X		X	+					X	X		X		
California gull (*Larus californicus*)	X	X	+	X	+			X	+				X	X		X		
Herring gull (*Larus argentatus*)	X	X							X				X	X		X		
Thayer's gull (*Larus thayeri*)	X									X			X					
Western gull (*Larus occidentalis*)	X									X			X					
Glaucous-winged gull (*Larus glaucescens*)	X									X			X	X				
Black-legged kittiwake (*Rissa tridactyla*)	X									X			X					
Sabine's gull (*Xema sabini*)		X			X				X				X	X				
Gull-billed tern (*Sterna nilotica*)			X							X				X				
Caspian tern (*Sterna caspia*)	+	X	X	X	+			X	+				X	X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Common tern (<u>Sterna hirundo</u>)		+		X	+		X		+		X		X	X				
Arctic tern (<u>Sterna paradisaea</u>)				X						X			X					
Forster's tern (<u>Sterna forsteri</u>)	+	X	X	X	+			X	+				X	X		X		
Least tern (<u>Sterna antillarum</u>)			X							X				X				
Black tern (<u>Chlidonias niger</u>)		X	X	X				X					X	X		X		
Black skimmer (<u>Rynchops niger</u>)			X	X						X				X		X		
Rock dove* (<u>Columba livia</u>)	X	X	X	X	X		X				X						X	
Band-tailed pigeon (<u>Columba fasciata</u>)			X	X	X					X					X			
White-winged dove* (<u>Zenaida asiatica</u>)	+	X	X	X	+	X			+		X				X	X	X	X
Mourning dove* (<u>Zenaida macroura</u>)	X	X	X	X	X	X									X	X	X	X
Inca dove (<u>Columbina inca</u>)	X	X	X	X	X		X				X						X	
Common ground-dove* (<u>Columbina passerina</u>)	X	X	X	X	X		X								X	X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Yellow-billed cuckoo* (*Coccyzus americanus*)			X	X					X			X			X			
Greater roadrunner* (*Geococcyx californicus*)	X	X	X	X	X	X									X	X		X
Common barn-owl* (*Tyto alba*)	X	X	X	X	X		X								X	X		X
Western screech-owl* (*Otus kennicotti*)	X	X	X	X	X		X								X			X
Great horned owl* (*Bubo virginianus*)	X	X	X	X	X		X								X	X		X
Elf owl* (*Micrathene whitneyi*)		X	X	X					X			X			X			X
Burrowing owl* (*Athene cunicularia*)	+	X	X	X	+		X	+			X?					X		
Long-eared owl* (*Asio otus*)	X	X	+						X	+					X			
Short-eared owl (*Asio flammeus*)	X	X			X			X						X	X	X		
Northern saw-whet owl (*Aegolius acadicus*)	X									X					X			
Lesser nighthawk* (*Chordeiles acutipennis*)	+	X	X	X	+	X			+					X	X	X		X
Common nighthawk (*Chordeiles minor*)			X							X								

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Common poorwill* (<u>Phalaenoptilus</u> <u>nuttallii</u>)		X	X	X			X											X
Black swift (<u>Cypseloides</u> <u>niger</u>)		X								X								
Chimney swift (<u>Chaetura</u> <u>pelagica</u>)			X							X								
Vaux's swift (<u>Chaetura</u> <u>vauxi</u>)		X		X				X						X	X			
White-throated swift* (<u>Aeronautes</u> <u>saxatalis</u>)	X	X	X	X	X		X							X		X		X
Broad-billed hummingbird (<u>Cyanthus</u> <u>latirostris</u>)	+			X	X				X	+					X		X	
Black-chinned hummingbird* (<u>Archilochus</u> <u>alexandri</u>)		X	X	X	+	X			+						X		X	X
Anna's hummingbird* (<u>Calypte</u> <u>anna</u>)	X	+	+	X	X		X	+			X				X		X	
Costa's hummingbird* (<u>Calypte</u> <u>costae</u>)	X	X	+	+	+			X	+						X		X	X
Calliope hummingbird (<u>Stellula</u> <u>calliope</u>)		X							X								X	
Broad-tailed hummingbird (<u>Selasphorus</u> <u>platycercus</u>)		X								X					X			
Rufous hummingbird (<u>Selasphorus</u> <u>rufus</u>)		+	+	X	+		X	+							X		X	

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Allen's hummingbird (*Selasphorus sasin*)	X		X	X						X					X		X	
Belted kingfisher (*Ceryle alcyon*)	X	X	+	+	X		X			+				X	X			
Lewis' woodpecker (*Melanerpes lewis*)	X	X			X				X						X	X		
Acorn woodpecker (*Melanerpes formicivorus*)			X		X					X					X			
Gila woodpecker* (*Melanerpes uropygialis*)	X	X	X	X	X			X				X			X		X	X
Yellow-bellied sapsucker (*Sphyrapicus varius*)	X	X			X				X						X			
Red-naped sapsucker (*Sphyrapicus nuchalis*)	X	X			X		X								X			
Red-breasted sapsucker (*Sphyrapicus ruber*)	X	X			X				X						X			
Williamson's sapsucker (*Sphyrapicus thyroideus*)	X		X							X					X			
Ladder-backed woodpecker* (*Picoides scalaris*)	X	X	X	X	X	X									X			X
Northern flicker (*Colaptes auratus*)	X	X	+	+	X	X			+						X			X
Gilded northern flicker* (*C. a. mearnsi*)	X	X	X	X	X				X			X			X			X

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Olive-sided flycatcher (<u>Contopus borealis</u>)		X		X				X							X			
Greater pewee (<u>Contopus pertinax</u>)	X								X						X			
Western wood-pewee (<u>Contopus sordidulus</u>)		X		+		X	+								X	X		
Willow flycatcher* (<u>Empidonax traillii</u>)		X	+	X				X		+		X			X			
Hammond's flycatcher (<u>Empidonax hammondii</u>)	+	X		+	+		X		+						X			
Dusky flycatcher (<u>Empidonax oberholseri</u>)	X	+							X	+					X			
Gray flycatcher (<u>Empidonax wrightii</u>)	+	X			X			X	+						X			X
Western flycatcher (<u>Empidonax difficilis</u>)	+	X	+	X	X		X		+						X			
Black phoebe* (<u>Sayornis nigricans</u>)	X	X	+	+	X	X	+							X	X	X		
Eastern phoebe (<u>Sayornis phoebe</u>)	X	X			X				X						X	X		
Say's phoebe* (<u>Sayornis saya</u>)	X	X	+	+	X	X		+							X	X		X
Vermilion flycatcher* (<u>Pyrocephalus rubinus</u>)	X	+	+	X	X			X	+			X			X	X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Dusky-capped flycatcher (<u>Myiarchus tuberculifer</u>)					X					X					X			
Ash-throated flycatcher* (<u>Myiarchus cinerascens</u>)	+	X	X	X	+	X		+							X			X
Brown-crested flycatcher* (<u>Myiarchus tyrannulus</u>)			X	X				X			X				X		X	X
Tropical kingbird (<u>Tyrannus melancholicus</u>)		X	X	X	X					X					X	X		
Cassin's kingbird* (<u>Tyrannus vociferans</u>)		+	+	+	X				X	+					X	X		
Thick-billed kingbird (<u>Tyrannus crassirostris</u>)	X			X						X					X			
Western kingbird* (<u>Tyrannus verticalis</u>)		X	X	X	+	X		+							X	X		
Eastern kingbird (<u>Tyrannus tyrannus</u>)				X						X					X	X		
Scissor-tailed flycatcher* (<u>Tyrannus forficatus</u>)			X	X	X				X						X	X		
Horned lark* (<u>Eremophila alpestris</u>)	X	+	+	X	X	X	+									X		
Purple martin (<u>Progne subis</u>)		X		X					X					X				
Tree swallow (<u>Tachycineta bicolor</u>)	X	X	+	X	X	X			+				X	X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Violet-green swallow* (*Tachycineta thalassina*)	+	X	+	X	X		X		+				X		X	X		X
Northern rough-winged swallow* (*Stelgidopteryx serripennis*)	+	X	X	X	+	X		+					X	X		X		
Bank swallow (*Riparia riparia*)	+	X	+	X	+			X		+			X	X		X		
Cliff swallow* (*Hirundo pyrrhonota*)		X	X	X		X							X	X		X		X
Barn swallow (*Hirundo rustica*)	+	X		X	X	X			+				X	X		X		
Steller's jay (*Cyanocitta stelleri*)	X				X					X					X			
Scrub jay (*Aphelocoma coerulescens*)	X	X	+	X	X				X	+					X			
Pinyon jay (*Gymnorhinus cyanocephalus*)					X					X					X			
Clark's nutcracker (*Nucifraga columbiana*)				X	X					X					X			
American crow (*Corvus brachyrhynchos*)	X				X		X				X				X	X		
Common raven (*Corvus corax*)	X	X	X	X	X		X									X		X
Mountain chickadee (*Parus gambeli*)	X				X					X					X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Bridled titmouse (*Parus wollweberi*)		X								X					X			
Verdin* (*Auriparus flaviceps*)	X	X	X	X	X	X									X		X	X
Bushtit (*Psaltriparus minimus*)	X				X				X						X			X
Red-breasted nuthatch (*Sitta canadensis*)	X	X		X	X				X						X			
White-breasted nuthatch (*Sitta carolinensis*)	X	X			X					X					X			
Pygmy nuthatch (*Sitta pygmaea*)					X					X					X			
Brown creeper (*Certhia americana*)	X	X			X			X							X			
Cactus wren* (*Campylorhynchus brunneicapillus*)	X	X	X	X	X		X								X			X
Rock wren* (*Salpinctes obsoletus*)	X	X	X	X	X		X											X
Canyon wren* (*Cartherpes mexicanus*)	X	X	X	X	X			X										X
Bewick's wren* (*Thryomanes bewickii*)	X	+	+	+	X		X	+			X				X			X
House wren (*Troglodytes aedon*)	X	X		X	X		X							X	X	X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Winter wren (<u>Troglodytes troglodytes</u>)	X	X			X				X						X			
Marsh wren* (<u>Cistothorus palustris</u>)	X	X	+	X	X	X	+							X	X	X		
American dipper (<u>Cinclus mexicanus</u>)					X					X				X				
Golden-crowned kinglet (<u>Regulus satrapa</u>)	X	X			X				X						X			
Ruby-crowned kinglet (<u>Regulus calendula</u>)	X	X			X	X									X			X
Blue-gray gnatcatcher (<u>Polioptila caerulea</u>)	X	X		X	X		X								X			
Black-tailed gnatcatcher* (<u>Polioptila melanura</u>)	X	X	X	X	X	X									X			X
Western bluebird (<u>Sialia mexicana</u>)	X				X			X							X			X
Mountain bluebird (<u>Sialia currucoides</u>)	X				X			X							X	X		X
Townsend's solitaire (<u>Myadestes townsendi</u>)	X	X			X				X						X			
Swainson's thrush (<u>Catharus ustulatus</u>)		X						X							X			
Hermit thrush (<u>Catharus guttatus</u>)	X	X			X		X								X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Rufous-backed robin* (*Turdus rufopalliatus*)	X	X			X					X					X		X	
American robin (*Turdus migratorius*)	X	X	+	+	X	X			+						X		X	
Varied thrush (*Ixoreus naevius*)	X	X			X				X						X			
Gray catbird (*Dumetella carolinensis*)				X						X					X			
Northern mockingbird* (*Mimus polyglottos*)	X	X	+	+	X	X	+								X	X	X	
Sage thrasher (*Oreoscoptes montanus*)	X	X		+	+		X		+						X	X		X
Brown thrasher (*Toxostoma rufum*)	X	X			X					X					X			
Bendire's thrasher (*Toxostoma bendirei*)	X	X	X	X	X				X						X			X
Curve-billed thrasher (*Toxostoma curvirostre*)	X			X	X				X						X			X
Crissal thrasher* (*Toxostoma crissale*)	X	X	X	X	X	X									X	X		
Le Conte's thrasher (*Toxostoma lecontei*)	X				X					X								X
Water pipit (*Anthus spinoletta*)	X	X			X	X								X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Sprague's pipit (*Anthus spragueii*)	X	X			X				X		X					X		
Bohemian waxwing (*Bombycilla garrulus*)	X	X								X					X		X	
Cedar waxwing (*Bombycilla cedrorum*)	X	X	+		+		X		+						X		X	
Phainopepla* (*Phainopepla nitens*)	X	X	+	+	X	X			+						X			X
Northern shrike (*Lanius excubitor*)	X				X					X					X	X		
Loggerhead shrike* (*Lanius ludovicianus*)	X	X	+	X	X	X	+								X	X		X
European starling* (*Sturnus vulgaris*)	X	X	X	X	X	X					X			X	X	X	X	X
Bell's vireo* (*Vireo bellii*)	+	X	X	X	+			X	+			X			X			
Gray vireo (*Vireo vicinior*)		X			X					X					X			
Solitary vireo (*Vireo solitarius*)	+	X		X	X		X		+						X		X	
Yellow-throated vireo (*Vireo flavifrons*)					X					X					X			
Hutton's vireo (*Vireo huttoni*)	X				X				X						X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Warbling vireo (_Vireo gilvus_)		X		X	X	X									X			
Red-eyed vireo (_Vireo olivaceus_)			X	X						X					X			
Blue-winged warbler (_Vermivora pinus_)				X						X					X			
Golden-winged warbler (_Vermivora chrysoptera_)					X					X					X			
Tennessee warbler (_Vermivora peregrina_)	X	X			X					X					X			
Orange-crowned warbler (_Vermivora celata_)	X	X		X	X		X								X			
Nashville warbler (_Vermivora ruficapilla_)	+	X		X			X			+					X			
Lucy's warbler* (_Vermivora luciae_)		X	X	+		X		+							X			
Northern parula* (_Parula americana_)	X	X	X		X				X						X			
Yellow warbler* (_Dendroica petechia_)	+	X	+	X	+		X		+			X			X			
Chestnut-sided warbler (_Dendroica pensylvanica_)	X				X				X						X			
Magnolia warbler (_Dendroica magnolia_)	X				X					X					X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Cape May warbler (<u>Dendroica</u> <u>tigrina</u>)				X						X					X			
Black-throated blue warbler (<u>Dendroica</u> <u>caerulescens</u>)	X				X					X					X			
Yellow-rumped warbler (<u>Dendroica</u> <u>coronata</u>)	X	X	+	+	X	X		+						X	X	X	X	
Black-throated gray warbler (<u>Dendroica</u> <u>nigrescens</u>)	+	X			X		X		+						X			
Townsend's warbler (<u>Dendroica</u> <u>townsendi</u>)	+	X		X	X		X			+					X			
Hermit warbler (<u>Dendrioca</u> <u>occidentalis</u>)		X		X	X			X							X			
Black-throated green warbler (<u>Dendroica</u> <u>virens</u>)					X					X					X			
Yellow-throated warbler (<u>Dendroica</u> <u>dominica</u>)				X						X					X			
Grace's warbler (<u>Dendroica</u> <u>graciae</u>)	X									X					X			
Palm warbler (<u>Dendroica</u> <u>palmarum</u>)				X	X					X					X			
Bay-breasted warbler (<u>Dendroica</u> <u>castanea</u>)			X		X					X					X			
Blackpoll warbler (<u>Dendroica</u> <u>striata</u>)		X	X		X					X					X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Black-and-white warbler (_Mniotilta varia_)	X	X		X	X				X						X			
American redstart (_Setophaga ruticilla_)	X	X	X	X	X				X						X			
Prothonotary warbler (_Protonotaria citrea_)		X			X					X					X			
Worm-eating warbler (_Helmitheros vermivorus_)		X		X						X					X			
Ovenbird (_Seiurus aurocapillus_)	X		X	X	X					X					X			
Northern waterthrush (_Seiurus noveboracensis_)	X	X		X	X					X					X			
Louisiana waterthrush (_Seiurus motacilla_)				X						X					X			
Kentucky warbler (_Oporonis formosus_)			X							X					X			
MacGillivray's warbler (_Oporonis tolmiei_)		X		X	X		X								X			
Common yellowthroat* (_Geothlypis trichas_)	+	+	X	X	+	X	+								X			
Hooded warbler (_Wilsonia citrina_)			X							X					X			
Wilson's warbler (_Wilsonia pusilla_)	+	X		X	+	X			+						X			

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Painted redstart (*Myioborus pictus*)	X			X	X					X					X			
Yellow-breasted chat* (*Icteria viren*)			X	X			X					X			X			
Hepatic tanager (*Piranga flava*)	X	X			X					X					X			
Summer tanager* (*Piranga rubra*)	+	+	X	X	+			X		+		X			X			
Scarlet tanager (*Piranga olivacea*)					X					X					X			
Western tanager (*Piranga ludoviciana*)		X	+	X	+		X		+						X			X
Northern cardinal* (*Cardinalis cardinalis*)	X	X	X	X	X				X		X				X		X	
Pyrrhuloxia (*Cardinalis sinuatus*)			X							X					X			X
Rose-breasted grosbeak (*Pheucticus ludovicianus*)			X	+	+				X	+					X		X	
Black-headed grosbeak (*Pheucticus melanocephalus*)		X	+	X			X		+						X		X	
Blue grosbeak* (*Guiraca caerulea*)			X	X	+	X			+					X	X	X	X	
Lazuli bunting (*Passerina amoena*)		X	+	X		X			+						X	X		

(Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Indigo bunting* (Passerina cyanea)			X	X				X				X			X			
Varied bunting (Passerina versicolor)	X			X							X				X			
Painted bunting (Passerina ciris)				X	X					X					X			
Dickcissel (Spiza americana)				X						X					X	X		
Green-tailed towhee (Pipilo chlorurus)	X	X			X			X							X	X		
Rufous-sided towhee (Pipilo erythrophthalmus)	X	+			X			X		+					X			
Abert's towhee* (Pipilo aberti)	X	X	X	X	X	X									X	X	X	
Cassin's sparrow (Aimophila cassinii)		X								X					X			
American tree sparrow (Spizella arborea)	X				X					X				X	X			
Chipping sparrow (Spizella passerina)	X	X		X	X			X							X	X	X	
Clay-colored sparrow (Spizella pallida)				X						X						X	X	
Brewer's sparrow (Spizella breweri)	X	X		X	X	X									X	X		X

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Black-chinned sparrow (*Spizella atrogularis*)	X			X						X					X			X
Vesper sparrow (*Pooecetes gramineus*)	X	X		+	X	X	+									X		
Lark sparrow* (*Chondestes grammicus*)	X	X	+	X	X			X	+							X	X	
Black-throated sparrow* (*Amphispiza bilineata*)	+	X	X	X	+			X	+									X
Sage sparrow (*Amphispiza belli*)	X	X			X			X							X			X
Lark bunting (*Calamospiza melanocorys*)	X				X				X							X		
Savannah sparrow (*Passerculus sandwichensis*)	X	X		+	X	X	+									X		
Grasshopper sparrow (*Ammodramus savannarum*)	X	X			X				X							X		
Le Conte's sparrow (*Ammodramus leconteii*)					X					X						X		
Sharp-tailed sparrow (*Ammodramus caudacutus*)		X								X				X				
Fox sparrow (*Passerella iliaca*)	X	X			X				X					X	X			
Song sparrow* (*Melospiza melodia*)	X	+	+	+	X	X	+							X	X	X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Lincoln's sparrow (<u>Melospiza lincolnii</u>)	X	+			X	X	+							X	X	X		
Swamp sparrow (<u>Melospiza georgiana</u>)	X	X			X				X					X	X			
White-throated sparrow (<u>Zonotrichia albicollis</u>)	X	X			X				X						X	X		
Golden-crowned sparrow (<u>Zonotrichia atricapilla</u>)	X	X			X				X						X	X		X
White-crowned sparrow (<u>Zonotrichia leucophrys</u>)	X	X			X	X									X	X	X	X
Harris' sparrow (<u>Zonotrichia querula</u>)	X	X			X				X							X		
Dark-eyed junco (<u>Junco hyemalis</u>)	X	X			X			X							X	X		
McCown's longspur (<u>Calcarius mccownii</u>)	X				X					X						X		
Lapland longspur (<u>Calcarius lapponicus</u>)	X				X				X							X		
Chestnut-collared longspur (<u>Calcarius ornatus</u>)	X	X			X				X							X		
Bobolink (<u>Dolichonyx oryzivorus</u>)			X	X						X						X		
Red-winged blackbird* (<u>Agelaius phoeniceus</u>)	X	X	X	X	X	X								X		X		

(Continued)

APPENDIX B. (Continued)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Eastern meadowlark (<u>Sturnella magna</u>)	X				X					X						X		
Western meadowlark* (<u>Sturnella neglecta</u>)	X	X	+	+	X	X	+									X		
Yellow-headed blackbird* (<u>Xanthocephalus xanthocephalus</u>)	+	X	X	X	+		X	+						X		X		
Rusty blackbird (<u>Euphagus carolinus</u>)	X	X			X					X					X			
Brewer's blackbird (<u>Euphagus cyanocephalus</u>)	X	X		+	X	X	+								X	X	X	
Great-tailed grackle* (<u>Quiscalus mexicanus</u>)	X	X	X	X	X		X				X			X		X	X	
Common grackle (<u>Quiscalus quiscula</u>)			X							X					X	X		
Bronzed cowbird* (<u>Molothrus aeneus</u>)			X						X		X						X	
Brown-headed cowbird* (<u>Molothrus ater</u>)	X	X	X	X	X	X					X			X	X	X	X	
Orchard oriole (<u>Icterus spurius</u>)	X	X			X					X					X			
Hooded oriole* (<u>Icterus cucullatus</u>)		X	X	X	+		X		+		X				X		X	
Northern oriole* (<u>Icterus galbula</u>)		X	X	+		X		+							X	X	X	

(Continued)

APPENDIX B. (Concluded)

Species	Seasonal presence					General abundance					Change from historical status		Primary habitats					
	Wi	Sp	Su	LS	Fa	C	FC	U	R	Acc	Inc.	Dec.	O	M	R	A	U	D
Scott's oriole (_Icterus parisorum_)			X							X								X
Purple finch (_Carpodacus purpureus_)	X				X				X						X		X	
Cassin's finch (_Carpodacus cassinii_)	X				X					X					X			
House finch* (_Carpodacus mexicanus_)	X	X	X	X	X	X									X	X	X	X
Red crossbill (_Loxia curvirostra_)				X	X					X					X		X	
Pine siskin (_Carduelis pinus_)	X	X			X			X							X			
Lesser goldfinch* (_Carduelis psaltria_)	X	X	+	+	X		X	+							X		X	
Lawrence's goldfinch* (_Carduelis lawrencei_)	X	X	+	+	X			X	+						X			
American goldfinch (_Carduelis tristis_)	X	X			X			X							X	X		
Evening grosbeak (_Coccothraustes vespertinus_)		X		X					X						X		X	
House sparrow* (_Passer domesticus_)	X	X	X	X	X	X					X					X	X	

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Abstract (Limit: 200 words)

This report reviews and synthesizes ecological information on the Lower Colorado River from the Davis Dam to the Mexico-United States border. It describes past and present environmental conditions in the River and on adjacent riparian lands along the River. The River and adjacent floodplains have been greatly changed, generally to the detriment of native flora and fauna. Native riparian woodlands have decreased dramatically as a result of agricultural conversion, and the most common species of tree along the River is now exotic saltcedar. Native wildlife populations have been seriously impacted by these land use and habitat changes. Native fisheries have been similarly impacted by changes in the flow and quality of water in the River resulting from upstream impoundments, diversion, and irrigation return flows. Opportunities exist for reversing these trends through alteration in the management of the River; however, it will require changes in the way political, social, and economic decisions are made in this region.

Document Analysis a. Descriptors
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