DRAFT

MEMORANDUM

Date: February 22, 2000

To: The Honorable Chair and Members
Pima County Board of Supervisors

From: C.H. Huckelberry
County Administrator

Re: *Desert Ironwood Primer*

I. Report

It is a privilege to forward the attached report entitled *Desert Ironwood Primer* from the Arizona-Sonora Desert Museum in coordination with the Sonoran Desert Conservation Plan effort. Written by Dr. Gary Nabhan and other scientists, the *Desert Ironwood Primer* is the first study that takes a comprehensive view of ironwood habitats in both the United States and Mexico, evaluating the ecological and cultural resources supported by the ancient ironwood tree. Divided into two parts, the study provides an overview of the history and ecology of desert ironwood, and a discussion of the binational research effort undertaken to produce the report. A number of recommendations are offered by the authors, which I support as part of the Sonoran Desert Conservation Plan and as interim measures to offer protection to areas identified by the authors as having extraordinary ecological significance.

II. Ecological Significance

The *Desert Ironwood Primer* establishes the importance of ironwood as a habitat modifying keystone species and nurse plant that has a role in supporting the biodiversity of over 500 Sonoran Desert species, including the endangered cactus ferruginous pygmy-owl. At the site specific level, biodiversity associated with ironwood can be even higher. The ironwood-bursage habitat in the Silverbell Mountains of Pima County is associated with 674 species, including 64 mammals and 57 bird species. Some of the highlights from the report include these points:

- Ironwood "ranks among the most ecologically and economically important plant species in the region. ... It's influence stands out in two biotic communities: 1) ancient cactus and legume forests of desertscrub on rocky bajadas and alluvium in adjacent valleys; and 2) xeroriparian habitats, which occur as narrow curving corridors along ephemeral and intermittent watercourses in the driest portions of the Sonoran Desert." (P. 4)

- "Ironwood generates a chain of influences on associated understory plants, affecting their dispersal, germination, establishment, and rates of growth. ... Ironwood is the dominant nurse plant in some subregions of the Sonoran Desert." (P. ii)

- "The mere presence of ironwood and other legume trees can increase the number of bird species in desertscrub habitat by 63%." (P. ii)

- "Recent studies show that without the protective cover of the desert legumes, the distributional ranges of saguaro, organ pipe, and senita cactus would retreat many miles, to more southern, frost-free areas." (P. iii)

- "Protecting ironwood habitat in Pima County, Arizona, will benefit a different mix of native species than would be conserved in ironwood habitats currently being protected on the islands or coasts of the Gulf of California." (P. v)

- "North of the U.S. - Mexico border, the highest ironwood densities we recorded per hectare came from Arizona Uplands sites in Pima County (Ragged Top, 35 trees/ha; Cocoraque and Saguaro National Park West 22 trees/ha)." (P. 14)

Ironwood Densities in Pima County	
Location	**Ironwood/Hectare**
Organ Pipe National Monument (Northern Areas)	37-90 ironwoods / hectare
Ragged Top (Silverbells)	35 ironwoods / hectare
Cocoraque (Brawley Wash)	21.25 ironwoods / hectare
Saguaro National Park West	21.25 ironwoods / hectare
Tortolitas	11.25 ironwoods / hectare
Mason Audubon Center, NW Tucson	11.25 ironwoods / hectare
Cabaza Prieta National Wildlife Refuge	11.25 ironwoods / hectare
Organ Pipe National Monument (cut areas)	2.5 ironwoods / hectare

- In general, densities in Mexico range from 1.25 to 30 trees per hectare. The report points out that "it appears ironwood densities ... are greater near the species' northernmost limits in the Arizona Uplands and Lower Colorado River Valley." (P. 14)

- "Lush riparian habitats, such as closed-canopy mesquite bosques, are often assumed to be the most threatened habitat type in this region. However, mounting evidence indicates that the biodiversity associated with xeroriparian habitats has become just as imperiled. At least 31 breeding bird species declined locally in riparian mesquite bosques within the last half-century. Thirty of these birds also spend part of the year in ironwood habitats." (P. 21-22)

- "The Ragged Top site ... contributed the highest levels of species richness [of the study], with six of the ten plots having the highest levels within the entire region." (P. 56-57)

III. Need for Greater Protection

The report points that the United States offers limited protection for ironwood, compared to Mexico, despite the importance of the ironwood stands to the species itself, and to the larger Sonoran Desert system.

The Ragged Top and Cocoraque Rock areas are identified in the report as priorities for new protection and for strengthened conservation management, since "within the region as a whole, the [Ragged Top, Ironwood Picnic Area, and Cocoraque sites] contribute the highest values of significance to biodiversity conservation." (P. 59).

IV. Recommendations

Pages 61 through 64 contain recommendations from the authors based on a decade of study by the science community.

The conservation related recommendations will be forwarded to the Science Technical Advisory Team for consideration as part of the Sonoran Desert Conservation Plan.

I have directed staff to formulate a proposal for the Board's consideration which incorporates to the extent possible the recommendations found on pages 62-64. These include:

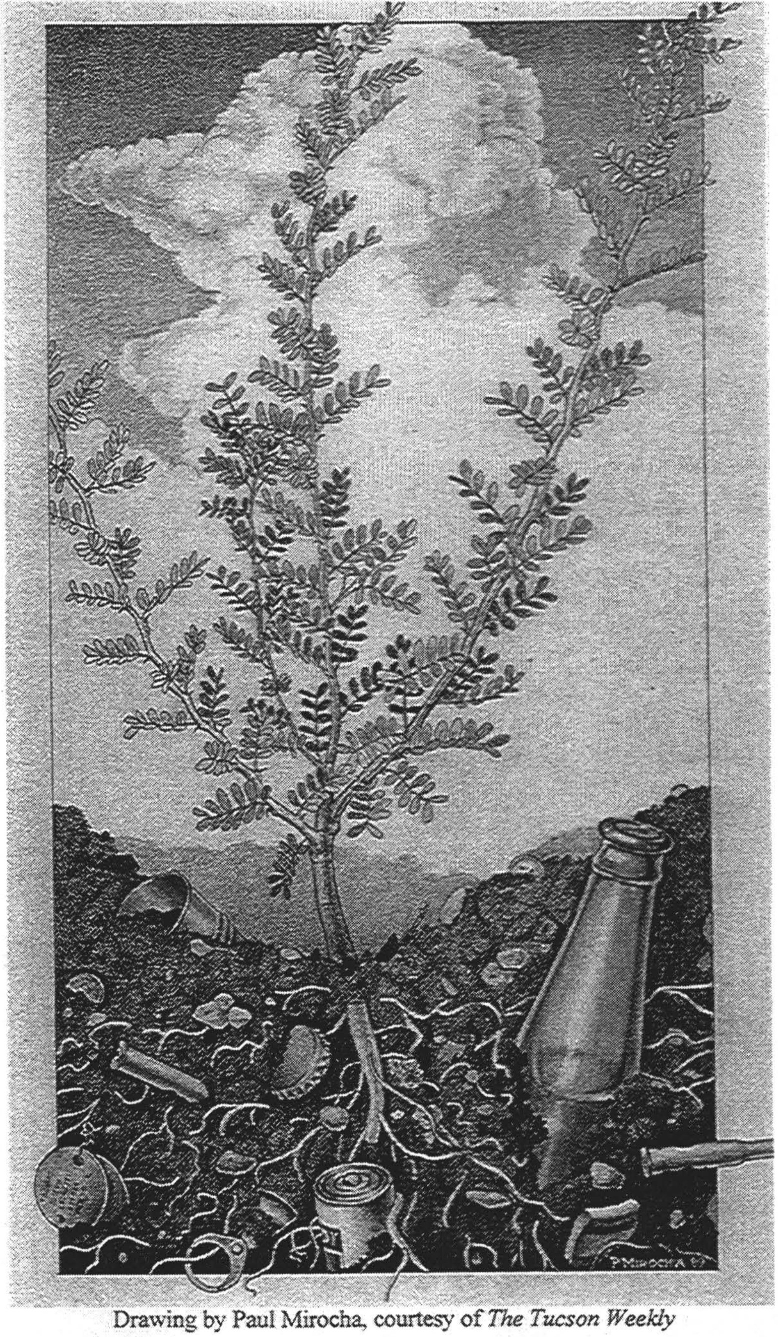
- Requiring assessments to determine the extent of ironwood destruction during the permitting process;
- Salvaging and relocating ironwood;
- Protecting the areas of highest density ironwood;
- Protecting and devising a corridor of stepping stone reserves within ironwood habitats for the benefit of species, including the pygmy-owl; and
- Planning and implementing protection strategies for ironwood as needed in wash, rocky slope and valley/plains ironwood habitats.

The *Desert Ironwood Primer* is the most comprehensive biological review that has emerged during the planning process for the Sonoran Desert Conservation Plan, and it points out the importance of understanding the value of our resource base within the larger context of natural systems. We look forward to more collaborations with the Arizona-Sonora Desert Museum and to basing policy proposals on the comprehensive science based analysis that we are privileged to see now, in the example of the attached *Desert Ironwood Primer.*

Attachment

Desert Ironwood Primer

Biodiversity and Uses Associated with Ancient Legume and Cactus Forests in the Sonoran Desert



Drawing by Paul Mirocha, courtesy of *The Tucson Weekly*

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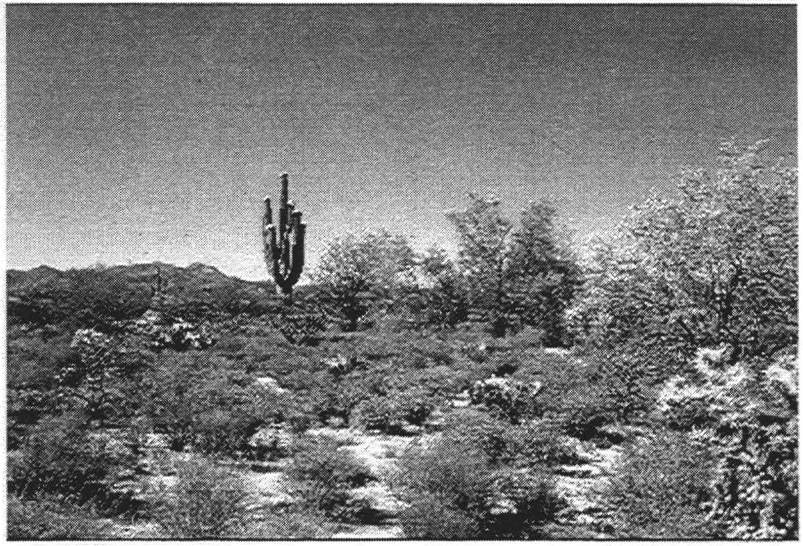

Ironwood trees in bloom in northwest Tucson, spring of 1998 (Michael Terrio photo, 1998).

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Founded in 1952, the **Arizona-Sonora Desert Museum** is a non-profit educational institution focusing on natural history and dedicated to fostering public appreciation, knowledge, and wise stewardship of the Sonoran Desert region.

ARIZONA SONORA DESERT MUSEUM

This report is the result of the work of many dedicated people and could not have been accomplished without immense efforts in cooperation and participation. Our gratitude goes to all those who helped and supported this project. Many people are listed, but there were others who offered kind words of support and encouragement, and we apologize if we have forgotten anyone.

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Base of ironwood in Pinal County, Arizona, photo by Patty West, 1999.

Desert Ironwood Primer
Executive Summary

Desert ironwood, or *palo fierro* in Spanish, provides many plant and animal species with habitat and resources critical to their survival. While scientists do not consider ironwood endangered or threatened as a species, its populations are dwindling rapidly and recover extremely slowly after exploitation. Its ecological importance comes largely through the roles it plays for over 500 other species in the Sonoran Desert. This report confirms ironwood's critical role as a *keystone species* and *nurse plant* in maintaining desert biodiversity and makes recommendations for its future protection.

Initiated with funding from the United States Department of Interior Border XXI project, our binational team launched this region-wide assessment to help guide land use decisions impacting ironwood habitat on both sides of the border. The study compiles nearly all previously published literature on ironwood ecology and analyzes data from 148 new study plots. The report consists of two parts: first, an overview of the ecological and historical background of desert ironwood; then a discussion of the first comprehensive binational study on perennial plant diversity of ironwood habitats in the Sonoran Desert, completed by our research team for this report.

Ironwood Ecology

Ironwood's range closely matches the boundaries of the Sonoran Desert, the only place in the world where it occurs. This hardy legume tree is the sole species in the genus *Olneya*. Ironwood is notable for its slow growth rates and extremely dense wood, which even sinks in water. While scientists consider ironwood to be the "old growth" tree of the desert, standard tree-ring dating of its wood is difficult. A regional group, the Ironwood Alliance, is currently pursuing alternative methods to date ironwoods. Estimates show some trees to be 800 years old, and it is likely that they live even longer. Though potentially long-lived, ironwoods face many threats, both as seedlings and as mature trees, from habitat fragmentation, grazing, woodcutting, and competition from exotic species.

Ironwoods bloom profusely in the spring and their blossoms lend a purple hue to the landscape. The pea-type pods mature at a time of year when little else is producing fruit in the Arizona Uplands, leading to a high dependence of wildlife on its seeds. Unlike other desert trees, ironwood rarely sheds all its leaves, so that its canopy provides shade and protection from frost and extreme heat year round.

Ironwood as a Keystone Species and Nurse Plant

Ironwood functions as a habitat modifying *keystone species*, that is, a species that exhibits strong influences on the distribution and abundance of associated species. Ironwood generates a chain of influences on associated understory plants, affecting their dispersal, germination, establishment, and rates of growth as well as reproduction. Scientists call these ecological dynamics "nurse plant ecology". Mesquite and palo verde also play this role, however, each tree caters to slightly different sets of plants in its "nursery". Ironwood is the dominant nurse plant in some subregions of the Sonoran Desert.

As nurse plants, ironwoods provide safe sites for seed dispersal, seedling protection from extreme cold and freezes, and sapling protection from extreme heat and damaging radiation. They also function as prey refugia. Finally, like other legumes, they alter the soil composition beneath their canopies, enriching the soil with nutrients such as nitrogen.

Ironwood, often the tallest tree in its habitat, attracts birds and other seed dispersers who roost in its branches and generate a literal "rain" of seeds and whole fruit. The mere presence of ironwood and other legume trees can increase the number of bird species in desertscrub habitat by 63%. Germination rates are higher and seedling survival rates better due to the improved soil conditions. Plant health, survival and growth are also improved by the shade and protection that ironwood's canopy offers. In turn, the greater diversity of plants growing in ironwood nurseries attracts a greater diversity of birds, both breeding and migratory.

The relationship between succulent cacti and ironwoods is especially well documented. Recent studies show that without the protective cover of desert legumes, the distributional ranges of saguaro, organ pipe, and senita cactus would retreat many miles, to more southern, frost-free areas. On freezing nights, the canopies of ironwood, below which the temperature may be 4° C warmer than in adjacent open areas, make the critical difference for vulnerable seedlings.

Ironwood plays a similar role in sheltering seedlings and saplings sensitive to extreme heat and radiation. Its canopy minimizes heat, damaging radiation, and water stress among plants established in its shade. When stripped of ironwood's protective cover above them, some cacti actually suffer sunburn and die.

In addition to serving as a buffer from such abiotic stresses as soil and moisture conditions, ironwood buffers nursery plants from some biotic stresses, especially that of herbivores. Thorny nurse plants can dramatically reduce the amount of predation on seedlings by large and small herbivores such as cows, rabbits, and rodents. In some places, the high number of animals that nest, burrow or seek refuge under ironwoods reduces this effect.

Ironwood as a Cultural Resource

The many indigenous cultures of the Sonoran Desert have long valued ironwood for its cultural, as well as ecological, resources. Traditional products and uses of ironwood include food, medicines, agricultural and household implements, and ceremonial and ritual uses. For most of these uses people utilized either renewable resources (pods, seeds, flowers) or salvaged wood from already dead trees, causing negligible impact to ancient ironwood forests.

The most well know contemporary cultural use of ironwood is by the Seri and Mexican carvers of coastal Sonora. The Seri began to carve elegant, abstract renderings of native animals in the 1960's. They always use dried, already dead ironwood branches for their handcrafted carvings. Nearby Mexican communities quickly copied the successful forms of the Seri carvings. However, their use of machines allows them to produce carvings at a rate that has rapidly depleted the local supply of ironwood. Attempts to protect the ironwood forests in this area have so far been unsuccessful.

The dense wood of ironwood burns extremely hot, making it the preferred fuelwood in communities in the northern Mexico, where any type of fuelwood is scarce. Mesquite charcoal production for export to the U.S. consumes even more ironwood. Ironwood grows in mixed stands with mesquite and is cut down as an illegal "by-catch" in much the same way tuna nets kill dolphins and other species, though its harvest is usually intentional rather than accidental. The Mexican charcoal industry boomed in the 1980's after the U.S. environmental laws banned highly polluting earthen pits, a grossly inefficient method where 60% of the energy is lost. Through the requests of the Seri and others, the Mexican government now requires permits for ironwood cutting, and no permits are given to cut ironwood for charcoal production. However the laws are difficult to enforce, and the incentive to cut dense, heavy ironwood is high among poor woodcutters paid by the weight of the wood they cut and collect.

Threats to Ironwood

Ironwood habitat faces many threats on both sides of the border, especially habitat fragmentation due to the rapid growth of cities such as Tucson, Yuma, Phoenix, Hermosillo and Mexicali, and the conversion of ironwood habitat to agricultural lands. The population explosion in the Sonoran Desert over that past 50 years has also led to increasing recreational impacts in ironwood habitat.

Woodcutting for charcoal production and fuelwood, as well as the carving industry, pose major threats in Mexico, where woodcutting alone causes an average 17% reduction in ironwood's dominance in the vegetation of the areas studied. The demand for wood even sends Mexicans over the

U.S. border to cut ironwood from Organ Pipe Cactus National Monument and other protected areas.

Grazing and competition by exotic species such as buffelgrass pose additional serious threats to ironwood, particularly in Mexico. Buffelgrass, a popular forage grass for cattle, is highly invasive. Studies show it decreases plant species richness and diversity in native plant communities and increases the frequency of fires. Fueled by buffelgrass, these hot burning wildfires destroy ironwood and other trees, shrubs and cacti.

Mexico granted ironwood "special protection status" in 1994 and protects it under a variety of law and regulations. In contrast, ironwood receives limited protection as a species in the two U.S. states in which it occurs, Arizona and California. Current laws regulating use and protection of ironwood need to be strengthened, and furthermore, enforced, in both the U.S. and Mexico.

Ironwood Diversity Study

After establishing the various potential benefits mature ironwood trees could provide to native flora and fauna in their habitats, our team surveyed 16 sites scattered across the Sonoran Desert to determine whether ironwood's presence influenced biodiversity in the same manner at all sites. Sampling the perennial vegetation in 148 new plots in 3 states, we determined ironwood's presence to be equally high in ecological importance in every subregion of the Sonoran Desert where we measured it.

In other words, the loss of ironwood from habitats in any Sonoran Desert subregion would diminish the overall lushness of vegetative cover, especially of vines. Nonetheless, the presence of ironwood in each subregion influences the diversity of associated plants in different ways, with great dissimilarities in the types of understory plants found below ironwoods in the Arizona Uplands and the Central Gulf Coast of Sonora. In short, protecting ironwood habitat in Pima County, Arizona, will benefit a different mix of native species than would be conserved in ironwood habitats currently being protected on the islands or coasts of the Gulf of California. Although ironwoods and mesquites found in the same habitats share most of the same understory species, ironwoods favor some vines and shrubs more than others, while mesquites favor a somewhat different mix.

The abundance and cover of understory plants found beneath ironwoods varies according to their location, from the banks of dry washes in valleys to those growing along small drainages on rocky slopes. In addition, all sizes of ironwoods do not necessarily function equally as nurse plants for other species. Young trees provide hardly any protective microenvironment at all, while the large, dense canopies of ancient trees can become too shady to allow much plant growth beneath them, and their higher branches allow cows to forage under them in grazed areas.

Recommendations

Using several different measures of species diversity, richness, and ecological importance, we have selected several sites as priorities for new protection and for strengthened conservation management. In the U.S. state of Arizona, the sites are: Ragged Top on the boundary of Pinal and Pima Counties; and the Cocoraque Rock and Ironwood Picnic Areas on either side of Brawley Wash in Avra Valley, Pima County. In Sonora, Mexico, the sites are: Punta Santa Rosa north of Kino Bay, and Tecomate on Tiburón Island, both on Seri Indian lands; the southern reaches of the Sierra El Pinacate north of Puerto Peñasco (Rocky Point); and Rancho El Carrizo, a private ranch and masked bobwhite quail refuge near Carbo, Sonora. Although other areas undoubtedly deserve further study and protection, these sites, with the already protected sites in Saguaro National Park, Cabeza Prieta National Wildlife Refuge, and Organ Pipe Cactus National Monument, could provide the cornerstones for a regional reserve network to protect the biodiversity associated with ironwood habitats in the Sonoran Desert.

In addition to the above recommendations for protection of specific locations, the report makes recommendations to guide future research, education, conservation, and sustainable use of ironwood and its habitats.

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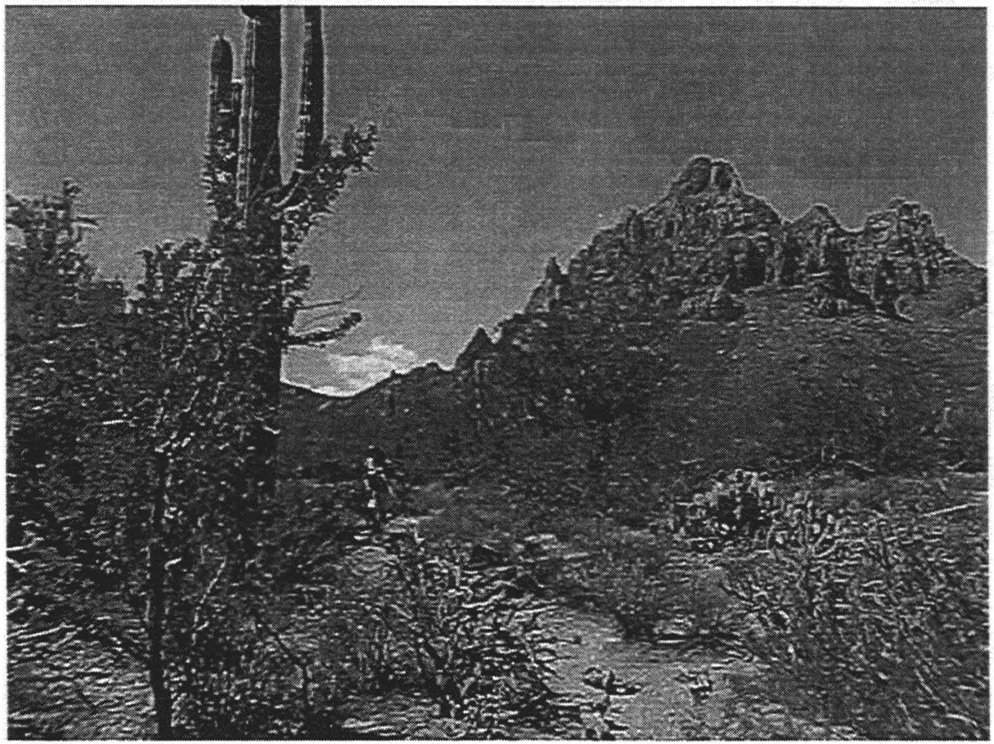

Ironwood habitat at Ragged Top Mountain, Pima County, Arizona, photo by Patty West 1999.

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Ironwood tree in El Pinacate Biosphere Reserve, photo by Patty West, 1999.

Part One: An Ecological and Historical Background of Ironwood

Introduction

The tree known in the U.S./México borderlands as desert ironwood (*Olneya tesota* Gray) is but one of many woody legumes found in washes and hillside drainages in the Sonoran Desert. It ranks among the most ecologically and economically important plant species in the region. As will be amply documented in this primer, it functions as a "nurse plant" and a "habitat-modifying keystone species" of benefit to many other species of flora and fauna. Its influence stands out in two biotic communities: 1) "ancient cactus and legume forests" of desertscrub on rocky bajadas and alluvium in adjacent valleys; and 2) "xeroriparian habitats", which occur as narrow curving corridors along ephemeral and intermittent watercourses in the driest portions of the Sonoran Desert (Nabhan and Carr 1994).

Of the many traditional and economic uses of ironwood, some uses reduce the ecological value of ancient ironwood forests, while others have a negligible effect (Nabhan 1992*a,* 1992*b*). The increasing area over which extractive economic uses occur has been of concern to conservation biologists in the United States and México for almost a decade (Molina and Solís-Garza 1988; Mellink, Nabhan and Suzán 1994). In addition, the rapid urban expansion of Tucson, Yuma, Phoenix, Mexicali, and Hermosillo is causing fragmentation of several impressive ironwood stands. Due to this fragmentation, scientists now perceive these ancient desert forests to be a dwindling component of our region's natural heritage (Nabhan and Carr 1994, Nabhan 1992*b*).

Because of the many land-use issues now impacting ironwood habitats in the binational Sonoran Desert, particularly in Pima County, Arizona, the Arizona-Sonora Desert Museum proposed a region-wide assessment to the United States Department of Interior. Border XXI approved funding to support this proposed project and collaborators during the summer of 1999. Those funds allowed the Museum staff to compile nearly all previously published literature on ironwood ecology, and to complete nearly 150 new ironwood habitat study plots. The research referred to in this overview can serve as baseline information for both further analysis and ongoing monitoring of ironwood habitat. In the meantime, we prepared this report to summarize the state of current knowledge about ironwood habitat for the benefit of residents of the Sonoran Desert in the United States and México.

We intend for this document to be an informational handbook that answers many of the basic questions asked by local citizens and resource managers about the need for ironwood conservation. Why is ironwood itself not considered an endangered species even though its populations are dwindling in many places? What endangered species in addition to the pygmy owl (*Glacidium brasilianum*) depend upon ironwood habitat? If México granted ironwood special protection status, why do ironwood products continue to be sold to American consumers? Does ironwood depletion in México make remaining ironwood habitat in the United States even more valuable? Do different sets of threats affect ironwood habitats on either side of the border? Is there anything relatively special or unique about ironwood habitats in the Arizona Uplands, or in Pima County's rapidly-developing foothills in particular?

In addition to these politically charged issues, some basic biological issues regarding ironwood will be addressed. How long do these trees live? Are the microhabitats under ironwood trees similar to those of other leguminous "nurse plants"? How many kinds of native plants and animals utilize these microhabitats? Do any of these associated species depend solely upon ironwood, or will they utilize mesquites and palo verdes if ironwood is lost from these habitats? Is there a cohesive guild of understory plants associated with ironwood throughout the Sonoran Desert region, or does the list of associated plants vary from subregion to subregion? Are ancient ironwood forests a cohesive habitat type or does ironwood grow and behave differently in a variety of physical settings? Does the presence of invasive weeds change the particular groups of native plants and animals associated with ironwood habitats?

We prepared this report under a cooperative agreement with the National Park Service, with the guidance of the staff at Saguaro National Park. We are particularly grateful to Mark Holden for serving as liaison throughout this process. Maeveen Behan and Bill Singleton of Pima County's administrative offices also coordinated this effort with the Sonoran Desert Conservation Plan effort. Contributors from IMADES/Sonora, the University of Arizona, Universidad Autonoma de Queretaro, the Tucson Audubon Society, Organ Pipe Cactus National Monument, Earthwatch, the Sierra El Pinacate y Desierto del Altar Biosphere Reserve, and the Seri Indian tribe assisted the Museum in fieldwork. The cover page lists all contributors to fieldwork, data analysis and report editing, while authors of each section are noted in the table of contents. The results, interpretations, recommendations and opinions expressed in this report have not necessarily received official endorsement from Pima County, the National Park Service, Department of Interior or other collaborating organizations, but are offered to stimulate further discussion based on current knowledge of ironwood ecology. We encourage readers to send us their comments, unpublished or published data from ironwood habitats, and any critiques they wish to offer. We will attempt to accommodate them, with proper acknowledgments, in any future editions of this document.

Understanding Ironwood as a Species

The tree legume known as ironwood, or *palo fierro,* is endemic to the Sonoran Desert and adjacent areas of coastal thornscrub. Botanist Asa Gray first described ironwood to the scientific world in 1854 as the sole species of the genus *Olneya.* A recent analysis, undertaken by Lavin (1988), of the systematic relationships of bean family members with butterfly-shaped flowers, continues to recognize *Olneya* as a unique, or monotypic, genus. It is marginally similar in morphology to only two other desert legume genera, peteria (*Peteria* sp.) and brushpea (*Genistidium* sp.). All three genera have narrowly elliptical leaves and less than 12 ovules (potential seeds) per pod. Several characteristics distinguish *Olneya*, including paired leaves, flower clusters on short shoots that extend from the middle of the stem (instead of the end of a branch), and pods more rounded than the pods of peteria and brushpea.

Ironwood is also related to the spineless desert shrub, *Coursetia.* All of these plants fall within the group of legumes characterized by the New Mexican locust (*Robinia neomexicana*), which occurs in semi-arid habitats at higher elevations. They are essentially tropical woody plants surviving in seasonally dry vegetation (Lavin 1988). Ironwood as a species evolved as the Sonoran Desert flora formed in the Miocene (23.7 to 5.3 million years ago) (Van Devender 2000), but most paleogeological records of ironwood date from the mid- to late Holocene (Appendix V).

> Probably the hardiest of all desert trees is the desert ironwood (*Olneya tesota*), which grows abundantly along dry stream beds in most parts of the Sonoran plains and on the low, hot desert land of southwestern Arizona and adjacent eastern California, and in Baja California to the tip of the peninsula. The brittle wood is so hard it soon dulls the sharpest tools; for this reason the Mexicans have called it palo de fierro ("tree of iron").
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> Edmund C. Jaeger, *The North American Deserts* (1957)

Because hundreds of thousands of individual plants survive over a large geographic range, scientists do not consider ironwood to be endangered or near extinction in either México or the United States. Nevertheless, ironwood is easily overexploited because of certain life history traits, primarily its slow growth rates and low levels of seedling establishment (Suzán 1994). Though ironwood as a species remains genetically and demographically viable today (Nabhan and Carr 1994), ironwood populations dwindle annually over tens of thousands of square kilometers. To understand the conservation status of ironwood habitats, we need to first summarize the life history traits of ironwood as well as its ecological attributes. We hope this analysis of the life history, adaptations, and geographical distribution of ironwood will help inform efforts to foster effective management of ironwood populations. As this report abundantly documents, ironwood populations play a key role sustaining other species and populations of the Sonoran Desert.

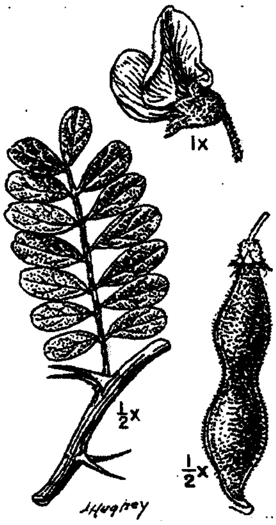


Figure 1: Ironwood from United States Department of Agriculture Forest Service Collection, Hunt Institute for Botanical Documentation, Carnegie Mellon University, Pittsburgh, P.A.

A woody perennial, ironwood may take the shape of either a multi-trunked shrub no more than two meters in height, or a canopy-forming tree with one thick trunk achieving heights up to 15 meters (Shreve and Wiggins 1964, Solís-Garza 1993, Arizona Register of Big Trees 2000). The largest known ironwood, located close to Gila Bend, measures 4.32 meters around its trunk, with a canopy height of 15 meters, and a crown spread of 14 meters (Arizona Register of Big Trees 2000).

The ironwood "leaf" is doubly divided into 4 to 12 pairs of narrowly elliptic leaflets called pinnae (Figure 1). Each leaf consists of two to four "fingers" with paired leaflets down the sides of each. This compound leaf has a pair of small curved spines at its attachment to the branch (Dimmitt 2000*b*). These leaflets have a bluish-green cast to them, producing a mottled canopy quite unlike the yellow-green of mesquites (*Prosopis* spp.) and palo verdes (*Parkinsonia* spp.) growing in the same region.

Ironwood's clusters of flowers bloom on the end of short shoots along the branches (Lavin 1988). During the season of flowering, its lavender, pink, or purple pea-shaped blossoms mix with the blue-green foliage and light-gray bark to create a turquoise-tinted canopy of singular beauty.

Ironwood grows extremely slowly, perhaps due to its low rates of photosynthesis that keep it from wasting soil moisture. Physiologists express these low rates as 12mg CO_2/dm^2 /hr (Szarek and Woodhouse 1977), much lower than mesquite or even palo verde. Such slow rates of biomass accumulation contribute to the remarkable density of its heartwood, surpassed only by one other tree species on earth.

The wood of ironwood, as its name suggests, is very hard and dense. Its heartwood rates a specific gravity measurement of 1.14, compared to the specific gravity of water at 1.0. Any wood, such as ironwood, will sink in water when its specific gravity exceeds that of water. This density indicates cell walls with very little air space between them, resulting in a high weight per volume. Each cubic meter of ironwood weighs 1060 kilograms (Solís-Garza and Espericueta 1997), second only to the tropical tree, lignum vitae (*Guaiacum officinale*) in weight per volume.

Because of its extraordinarily dense wood, dendrochronologists have found it difficult to calculate the age of ironwood by conventional tree-ring dating methods (see next section, Dating Ironwood). It is remarkably resistant to rotting, perhaps because its heartwood is rich in toxic chemicals that make it essentially non-biodegradable (Dimmitt 2000*b*). Ironwood trunks can persist on the desert floor for up to 1600 years, making them the preferred source of durable fence posts among many desert cultures (Dimmitt 2000*b*); (see Uses section).

Dating Ironwood

> The wood of the ironwood tree, impregnated with lignin and resins, is one of the hardest and heaviest woods in the world. However, the most distinctive characteristic of these grand trees is their longevity. Ironwood trees can live up to hundreds of years, and in some cases can be a thousand years old. They are a hallmark of the desert landscape, one which appears not to change with the passing of time. In this sense they become a part of the environment, like a rock or a wash, that is a constant witness to the activities of generation after generation of plants and animals—including those of humans.
>
> Alberto Burquéz, *Arbol de la Vida* (1999)

As of yet, scientists have been unable to accurately determine how long an ironwood tree can live. Several problems make tree-ring dating of ironwoods difficult. Since the wood is very hard, extra care must be taken in obtaining cores. Once they obtain cores, scientists cannot assume that each growth ring represents *annual* growth. With abundant winter and summer rains, ironwood may form narrow growth rings twice within one year, or not at all during drought years.

Fortunately, two other methods exist to date ironwoods: extrapolations from tracking growth of selected trees over several years, and radio-carbon dating of the oldest tissues in a few trees. From annual trunk diameter growth rates estimated by Turner (1963) and Suzán (1994), it is clear some ironwoods have persisted for more than 800 years, a projection consistent with an unpublished radiocarbon date obtained by the late Wes Ferguson (Suzán 1994). Most of this radial trunk diameter expansion, as well as growth in canopy volume, occurs after the summer rainy season begins. However, small increases in stem diameter do occur after winter rains in some years (Suzán *et al.* 1997). Ironwoods in most of Baja California undoubtedly grow more with the winter rains, which are more abundant there than summer rains. Currently, the Tucson Audubon Society and the Arizona Native Plant Society have teamed up to date ironwoods in the Tucson area.

Ironwood Flowering and Fruiting

Ironwood flowering and fruiting patterns generally occur in a south to north wave. Flowering and fruiting occur earlier in the southern, relatively frost-free states of Sonora and Baja California, México, than in the "north" of Arizona and California. Ironwood blossoms occur as early as March in the south, and as late as July in the north. The flowering period in each locality is often brief, lasting 10-18 days. During that time, ironwood attracts one generalist bee and two solitary specialist bees to its blossoms (Simpson 1977). Flowering intensities and dates vary from year to year (Table 1).

Table 1: Ironwood flowering and fruiting in Avra Valley near Tucson, Pima County

Month > Year	**April**	**May**	**June**	**July**	**Number of months in bloom**	**Number of months in full bloom**	**Amount of rainfall (inches)**
1983	----	----	++F+	+---	1.25	0.25	24.16
1984	----	----	+---	----	0.25	0.00	20.87
1985	----	-+++	+---	----	1.00	0.00	12.62
1987	----	----	----	----	0.00	0.00	9.95
1988	----	++F+	+----	----	1.25	0.25	10.21
1989	--+F	----	----	----	0.50	0.25	7.42
1990	----	+FF+	+---	----	1.25	0.50	19.18
1991	----	---+	++++	+---	1.50	0.00	12.34
1992	----	+FFF	F++-	----	1.75	1.00	20.69
1993	----	--++	+++-	----	1.25	0.00	19.08
1996	---+	FFF+	----	----	1.25	0.75	12.46
1997	----	+F++	++--	----	1.50	0.25	11.93
1998	----	---+	FF++	----	1.00	0.50	14.38
1999	---+	++FF	B+--	----	1.75	0.50	10.25

Months omitted had no flowering, F= in full flower, + = some flowering, - = no flowering, B= budding (From Arizona-Sonora Desert Museum unpublished records courtesy of Mark Dimmitt and Barb Skye)

In Tucson, flowers and fruit occur in most years, but are abundant only four years per decade (Dimmitt 2000*b*). This variable level of flowering and fruiting, along with differences in rainfall each year, may cause a pattern of mass seed production and seedling germination that occurs as occasional bursts. Suzán (1994) observed this unpredictable pattern of germination, known as "discrete episodic recruitment". Flowering and fruiting require considerable diversion of nutrients and energy from other parts of the plant. Branches that produce flowers often drop their leaves during bud formation, and re-leaf only when summer rains begin. In some years flowering does not occur (Dimmitt 2000*b*).

> *September*: The ironwood in the wash has undergone many changes over the course of the summer. In May it lost most of the leaves on its outer twigs and replaced foliage with flower buds. The buds burst in the first week of June, converting a ratty-looking tree to a plant of exquisite beauty, a temple seemingly composed entirely of radiant red-purple blooms aflame with color in the early morning light. The ironwood sustained its flowers for two weeks, during which it was visited daily by hundreds of digger bee females that harvested the pollen and nectar.
>
> As the flowers were pollinated and set seed, the faded petals dropped to the ground to carpet a circle of sand beneath the tree. Where once flowers bloomed, green seed pods grew, each just large enough to hold a couple of leguminous beans within a slightly furry case. Rock squirrels abandoned their boulder retreats and became arboreal again to pull the ironwood's seeds into their mouths.
>
> John Alcock, *Sonoran Desert Summer* (1990)

Once a bee such as *Centris pallida* pollinates ironwood flowers, they produce slightly curved, knobby pods that reach lengths of 3-6 cm. and widths of 8-9 mm. These easily shattered pods contain one to eight ovoid seeds, which are shiny, coffee-colored, and extremely hard-shelled when fully mature (Solís-Garza and Espericueta 1997). The timing of ironwood seed maturation coincides with summer rains, increasing the probability of immediate germination (Shreve and Wiggins 1964). The seeds can mature and fall from their dried pods within four to eight weeks after pollination, from late June through August (Turner *et al.* 1995). Ironwood seeds are small and rather light compared to those of palo verde or mesquite, with 4,440-4840 seeds per kg. dry weight (Kraugman 1948 *in* Solís-Garza and Espericueta 1997).

The seeds are relatively high in protein and soluble fiber (Table 2), and while they contain some anti-nutritional factors, are not "mildly toxic" as Dimmitt (2000*b*) suggests. Like the tannins in ironwood foliage, the bitter chemicals in ironwood seeds serve as deterrents to herbivores, reducing palatability and digestibility.

Interestingly, flood-leached seeds have fewer of these bitter chemicals that deter seed predation by herbivores or microbes prior to their germination. Native Americans, such as the Seri, mimicked this flood-leaching process by boiling ironwood seeds in two changes of water before eating the seeds (Felger and Moser 1985).

Table 2: Nutritional Value of Ironwood Seeds [1]

Nutritional Component	**Amount**	**Comments**
Crude Protein	19.5%	Low in methionine and cystine, but high in lysine
Ash (including fiber)	2.5%	High in soluble and insoluble fiber
Oil	10.3%	Mostly unsaturated fats in the form of linoleic (48%) and oleic acids (35%)
Digestibility	74%	Higher than that of beans, peas and soybeans
Anti-nutritional Factors	Various	Alkaloids, canavalins, saponins and lectins present in small quantities
Trypsine inhibitors	70 UTI/g	Heat-labile
Phenols	9.6%	Heat-labile

[1] Source: M. Ortega-Nieblas and L. Vázquez-Moreno. 1998. Universidad de Sonora and CIAD labs, Hermosillo, México.

Ironwood seeds mature at a time when little else is producing fruit in the Arizona Upland region (Dimmitt 2000*a*), leading to a high dependence of wildlife on the seeds (See later section, Ancient Ironwood Forests as Wildlife Habitat, and Appendix II). Many animals gather and store ironwood seeds in caches to be eaten later, including pocket mice (McAuliffe 1990). These mouse-like heteromyid rodents have characteristic fur-lined cheek pouches perfect for carrying large quantities of seeds. Roughly half of all new germinated seedlings found for plants such as jojoba (*Simmondsia chinensis*) and palo verde (*Parkinsonia microphylla)* occur in tight clusters near rodent burrows (McAullife 1990), and we suggest that ironwood seedlings may be established in rodent caches.

> By July the green pods had turned mottled brown, then deep chocolate, as the surviving beans matured and dried. The seeds and their covers fell to earth amidst the few remaining gray fragments of flower petals. Woodrats and pocket mice came at night to gather what the peccaries left untouched. The ironwood's outer limbs became bare again, with only a few curled pods dangling from branch tips and a collection of dusty green leaves on its inner arms. The dormant tree had joined the rest of us in waiting for the monsoon.
>
> John Alcock, *Sonoran Desert Summer* (1990)

Once germinated, ironwood seedlings are vulnerable to desiccation under the hot desert sun, and to browsing by pocket mice, rabbits, jackrabbits, packrats and ground squirrels (McAuliffe 1986). Ironwood seedlings unprotected by the nurse plant canopies of bursage (*Ambrosia deltoidea*), creosote (*Larrea tridentata*), or ironwood itself, may succumb to winter freezes at the northern and eastern limits of their range (Turner *et al.* 1997). Freezes may stress them enough to cause leaf loss, or may damage their growth tips, leaving upper branches looking burned.

When their roots gain some depth, ironwood seedlings and saplings establish symbiotic relationships with mycorrhizal fungi (Carrillo-Garcia *et al.* 1999) and nitrogen-fixing *Rhizobia* bacteria, which produce nodules on the ironwood's roots (Felker and Clark 1981). As they grow older and their roots deepen, ironwoods begin to "pump" nitrogen and water from sub-surface soil layers into the cells of ironwood leaves. Their leaf litter gradually enriches the nitrogen content of the upper soil beneath their canopies (Garcia-Moya and McKell 1970, Suzán 1994).

Mature trees are relatively deep-rooted and generally deficits in soil moisture availability do not stress them (Turner *et al.* 1995). Like other desert legume trees, ironwood trees adeptly conserve water during the extreme daytime heat and during dry seasons. Compared to other woody perennial plants, ironwoods lose less water through their leaves. Nilson *et al.* (1984) demonstrated this conservation of water in a study comparing water availability inside different plants growing in the same arid environment. In contrast to other woody perennials, researchers discovered the moisture levels of ironwood trees remain fairly constant from one dawn to the next and from winter to early summer (Klikoff 1967, Monson and Smith 1982). During long droughts the trees slough off leaves, limbs and rootlets to reduce their water needs. These studies suggest water-conserving characteristics, along with the deep roots of the ironwood, enable it survive and flourish in spite of prolonged droughts.

The water use efficiency of ironwood ranks with some of the most drought tolerant Sonoran Desert plants, such as creosote (*Larrea*), bursage (*Ambrosia*) and wolfberry (*Lycium* spp.) (Szarek 1979). Its conservative growth rate keeps ironwood from overspending its limited water budget. Taking into account their small leaves, diffuse canopies, and preference for arid and hyper-arid xeroriparian soils, it should be no surprise that ironwoods exhibit relatively low levels of annual net primary productivity

(55 g. dry weight/m^2/yr.) as well as low gross productivity: 7.42 kg. dry weight/tree/yr (Szarek 1979).

Ironwood Distribution, Density and Habitat Preferences

The geographic limits of ironwood distribution come as close to matching the geographic boundaries of the Sonoran Desert as those of any plant or animal (Shreve and Wiggins 1964). Ironwood barely reaches into the adjacent vegetation types known as Mohave desertscrub, coastal thornscrub, and foothills thornscrub. It occurs in five states and territories within the Sonoran Desert region: in southwestern Arizona, southeastern California, eastern Baja California Norte, throughout Baja California Sur, and throughout much of Sonora, México (Figure 2). Its reach stretches north along the Arizona-California border to 34 ° North near Parker, and its presumed southernmost limits on the mainland are near Chinobampo, Sonora (Turner *et al.* 1995). Overall, the southernmost populations of ironwood lie on the Gulf side of the Cape Region of Baja California Sur, almost reaching 23 ° North. A traveler up the peninsula from the Cape Region seldom sees ironwood reaching all the way to the Pacific coast, where summers are dry and relatively cool compared to the Gulf coast.

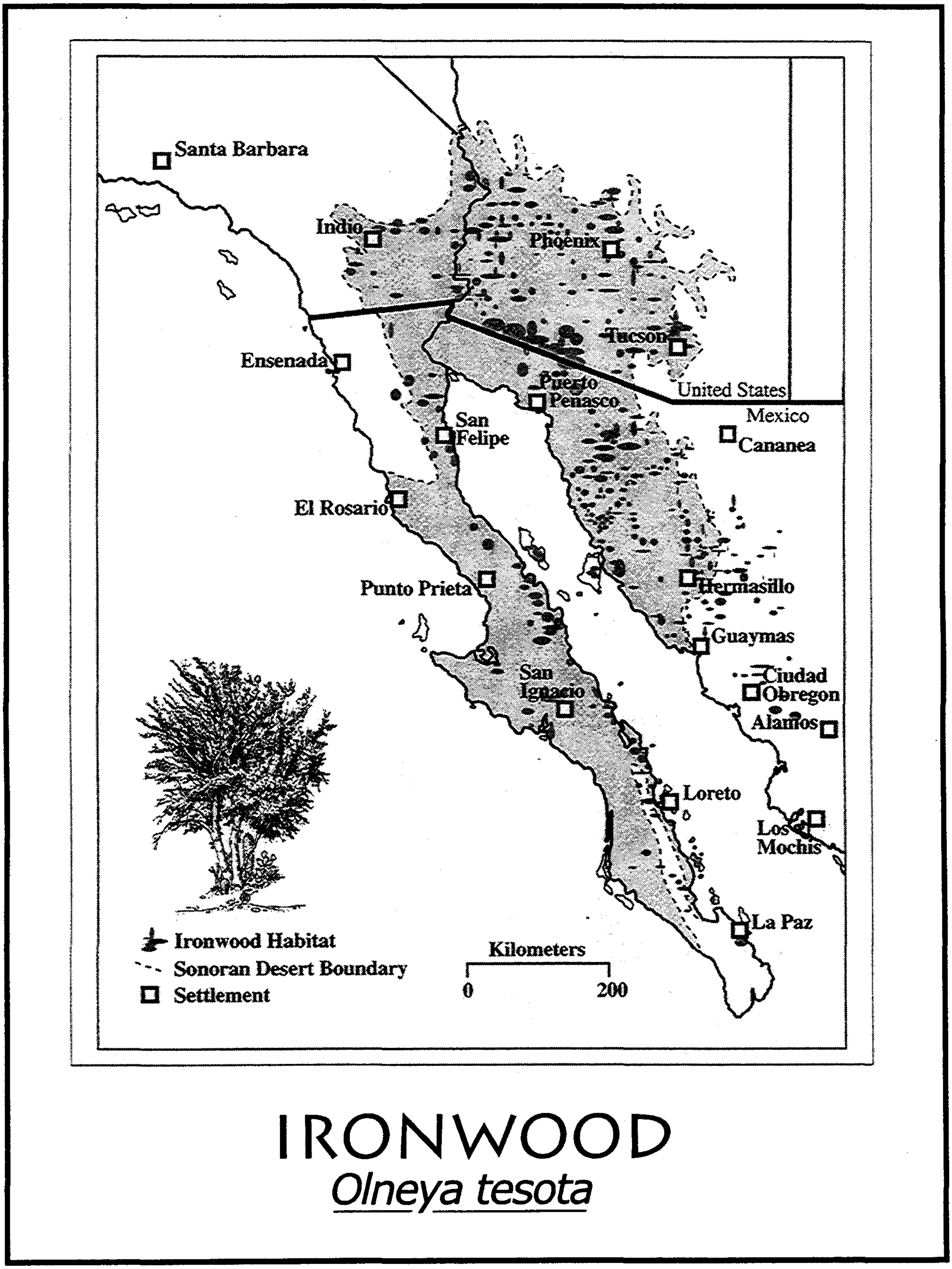


Figure 2: Map of ironwood distribution in the Sonoran Desert (courtesy of Bill Singleton, Pima County Administrative Office).

Ironwood populations occur from sea level to 1100 m. in elevation, where low winter temperatures and catastrophic freezes limit its distribution. These same factors generally limit its extension northward and eastward. However, dense ironwood populations found at higher elevations are near the northern limits of its range. Its elevational range at any latitude tapers down closer to sea level in the southern regions of Sonora. Near its northern reaches, ironwood grows best on rocky benches and slopes, above the valley bottoms where cold night air "pools" and causes damage to leaves and young branches (Turner *et al.* 1995).

Surprisingly, older, established ironwoods may be the largest trees in the desert for many kilometers in any direction, providing nectar, pollen, foliage, seeds and roosting or nesting resources for many animals. However, ironwood's relative importance as forage and habitat varies geographically. Variations in the density, height and habitat range of ironwood also exist across its distributional range.

Biogeographers currently divide the Sonoran Desert into six subdivisions, characterizing each of these regions by its own climatic peculiarities and dominant plant species. Ironwood occurs in all six subdivisions, but varies greatly in its density and relative dominance among these regions. We compiled densities of ironwood trees per hectare reported in other studies to compare with those derived from the stratified random plots in our own recent surveys (Table 3). Although land uses, soil types, weather and other intrinsic factors influence these densities, some interesting trends appeared.

North of the U.S.-México border, the highest ironwood densities we recorded per hectare came from Arizona Uplands sites in Pima County (Ragged Top, 35 trees/ha; Cocoraque and Saguaro National Park West, 22 trees/ha) (Table 3). Solís-Garza and Espericueta (1997) recorded ironwood densities of 15.2 trees/ha, in their "Zona Centro Norte" in the Lower Colorado River Valley subdivision. The single highest recorded density of ironwood in México is near Caborca, Sonora (Table 3). In that zone, the trees achieved an average height of 3.9 m. Combining data from their many plots in coastal and central Sonora, Solís-Garza and Espericueta (1997) found a mean density of 6.6 ironwood trees/ha. In summary, it appears ironwood densities, as well as elevational range, are greater near the species' northernmost limits in the Arizona Uplands and Lower Colorado River Valley.

Table 3: Ironwood densities at sites in Arizona, Sonora, and Baja California

Ironwoods/Ha	Location	County/Municipio	Source
3.75	Casa Grande/Stanfield Road	Pinal	This study
11.25	Tortolitas	Pima	This study
35	Ragged Top (Silverbells)	Pima	This study
11.25	Mason Audubon Center	Pima	This study
21.25	Saguaro National Park	Pima	This study
21.25	Cocaraque (Brawley Wash)	Pima	This study
0	Ironwood Picnic Area (Tucson Mountains)	Pima	This study
11.25	Cabeza Prieta National Wildlife Refuge	Pima	This study
37-90	Organ Pipe Cactus National Monument (northern areas)	Pima	Suzán 1994
2.5	Organ Pipe Cactus National Monument (cut areas)	Pima	This study
26-52	Sonoyta Border (cut areas)	P. Elias Calles	Suzán 1994
10-80*	Southern Sonoyta	P. Elias Calles	Paredes and López 1996
20-150*	Pinacate Biosphere Reserve	P. Elias Calles	Paredes and López 1996
1.25	Pinacate Biosphere Reserve	Puerto Peñasco	This study
30-230*	Caborca	Caborca	Paredes and López 1996
15.2	Centro-Norte (W. of Quitovac)	Caborca	Solís-Garza and Espericueta 1997
6.25	Rancho Carrizo near Carbo	Benjamin Hill	This study
4.8	Costa-Norte (Sierra Bacha)	Pitiquito	Solís-Garza and Espericueta 1997
5.5	Centro (Aravaipa Valley)	Pitiquito	Solís-Garza and Espericueta 1997
1.25	Tiburón Island (Tecomate)	Hermosillo	This study
0	Bahía Kino (cut area)	Hermosillo	This study
8.75	Bahía de los Angeles, BCS	Guerrero Negro	This study
2.5	Miguel Alemán/Calle 12	Hermosillo	This study
7.5	Bahía San Carlos near Guaymas	Guaymas	This study

* Extremely high values are from small sample plots extrapolated out to one hectare equivalents, and may not be relevant for comparative purposes

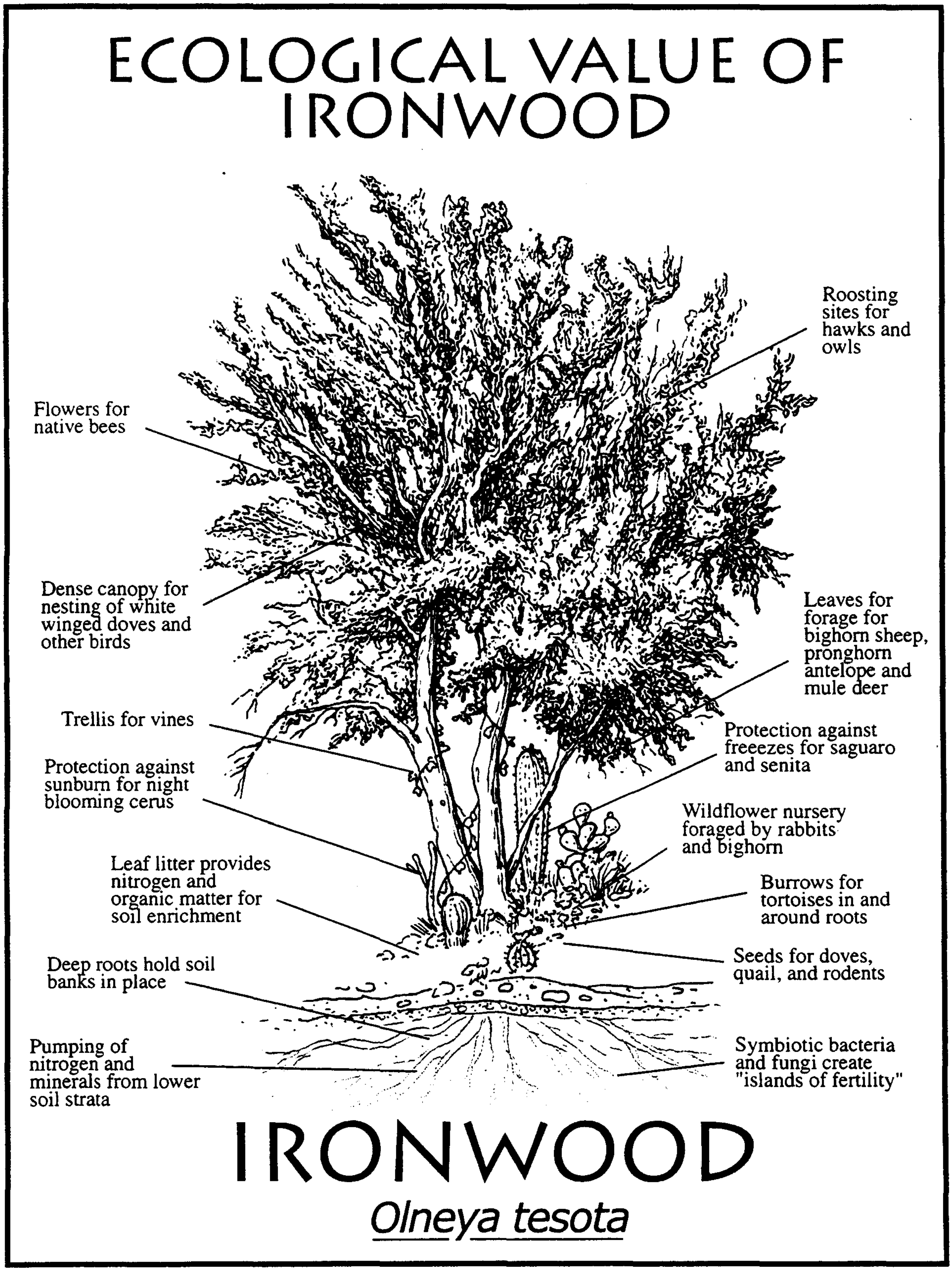


Figure 3. Ecological value of ironwood (courtesy of Bill Singleton, Pima County Administrative Office).

Ironwood as a Keystone Species

The following discussion focuses on the ways ironwood trees function as a habitat-modifying *keystone species*, that is, a species that exhibits strong influences on the distribution and abundance of associated species (Mills *et al.* 1993). Ironwood generates a chain of influences on associated understory plants, affecting their dispersal, germination, establishment, and rates of growth as well as reproduction. The ecological behavior of other plants in the "nurseries" under desert legume trees was first studied by Forrest Shreve (1911) in the Tucson Basin, and gave birth to a field of study now called "nurse plant ecology." Although the presence of nurse plants generally benefits understory species, competitive effects between the nurse and its nurslings exist which need to be considered as well (McAuliffe 1984*b*).

Ironwood as a Safe Site for Dispersal

Typically, an ironwood canopy has been functioning as a safe site for seed dispersal for time periods of three to four times longer than mesquite or palo verde canopies of the same volume. The long lifespan of ironwood trees and the stability of the microenvironments they create increase the probability that seeds might be dispersed to these "safe sites" for germination and establishment (Tewksbury and Petrovich 1984).

Olin *et al.* (1989) demonstrated the importance of desert legume trees as roost sites where birds and other seed dispersers generate a "rain" of viable seeds or whole fruit. Because ironwood and other legumes are often the tallest trees in desertscrub and xeroriparian vegetation (Vander Wall 1980), they function as the primary roosts in their landscape for both local breeding and migrating birds. Further, they and their nurseries make the structure of vegetation much more diverse, offering bird species a greater variety of desertscrub plants in which to nest, thereby potentially favoring bird dispersal of seeds (Vander Wall 1980, Suzán 1994).

These roosting birds subject the soil beneath ironwood canopies to "seed rain" from their feathers. Partially digested fruit from this "rain", or from defecation of other animals, are torn apart by animals seeking to gain sustenance while selecting out toxic or distasteful portions of the fruit. During thunderstorms and floods, seeds also flow into the areas underneath ironwoods. There they are trapped by exposed tree roots, or by the stems, roots and litter of understory herbs, vines and shrubs. We would therefore predict ironwood understories to be among the richest sites for seed dispersal and seedling establishment in desertscrub vegetation, but testing of this hypothesis has been piecemeal (Suzán 1994).

Ironwood as a Buffer from Extreme Cold and Freezes

Much of the initial recognition of nurse plants' importance to desert ecosystems occurred as a result of studies at the northern limits of saguaros and other cacti, where succulent plants are extremely vulnerable to damage by catastrophic freezes. During such freezes, a variety of species are killed over a large area and the temperatures plummet below 0° C for periods of 18 hours or more (Turner 1963; Shreve and Wiggins 1964; Gibson and Nobel 1986, Bowers 1980-81). Recent studies of cactus seedling vulnerability demonstrate that without the protective cover of desert legumes, the distributional ranges of saguaro (*Carnegiea gigantea*), organ pipe (*Stenocereus thurberi*) and senita (*Lophocereus schottii*) would retreat many kilometers, to more southerly, frost-free areas (Nobel 1980).

Ironwood foliage is also vulnerable to catastrophic freezes and exhibits "top-burn" after such events. Ironwood canopies provide microenvironments buffered from freezes for understory plants. Suzán (1994) determined the winter microenvironments under mature ironwood trees may be 4° C warmer than adjacent open environments and 1° C warmer than under other vegetation. In other words, when unsheltered desert areas reach freezing temperatures in winter, potentially damaging growth tips of vulnerable cacti or other plants, understory plants sheltered by ironwood canopies may remain well above the critical danger zone of temperature stress. This does not account for heat loss due to radiation, but indicates the relative difference in temperature between open areas and areas below the shelter of an ironwood canopy. One example of the effect of ironwood on the plants in its "nursery" is a 0.5 ° C increase in winter stem temperatures of the night blooming cereus (*Peniocereus striatus*) compared to cereus plants in the open. The early literature on the importance of nurse plants probably overemphasized their role in freeze protection relative to other functions they play, because these studies were done only where cacti were particularly vulnerable to catastrophic freezes (Steenburgh and Lowe 1977). It is now clear nurse plants such as ironwood play functional roles in creating "plant nurseries" even in frost-free areas.

Figure 4: The night blooming cereus cactus (*Peniocereus striatus*) in flower under an ironwood near Sonoyta, Sonora in 1992. Since that time, the ironwood has had branches cut and this cactus had declined due to greater exposure (G. Nabhan photo 1992).

Ironwood as a Buffer from Extreme Heat and Damaging Radiation

> It was most excellent to lie there on the cool blue-gray basalt under the tough old tree—ironwoods may be almost as long-lived as Methuselah—and watch the bees buzzing and sipping at the water's edge. The heat and glare beyond our little sheltering bower was terrific, stunning, exhausting; the heat waves looked dense enough to float a boat on. But here in the shade we knew peace of a sort, a happy bliss, ease of limb and mind.
>
> Edward Abbey, *Cactus Country* (1973)

As important as their role in frost protection is, nurse plant canopies also provide relief from heat and radiation stress. They reduce the exposure that leads to tissue damage and destruction of understory seedlings and saplings (Suzan 1994, Tewksbury *et al.* 1998). When stripped of ironwood's protective cover above them, some cacti actually suffer sunburn and die (Nabhan and Suzán 1994).

Damaging sunlight can be within or beyond the range of photosynthetically active radiation (PAR) associated with high temperatures (Gibson and Nobel 1986). Suzán (1994) demonstrated summer temperatures under ironwood canopies are much lower than ambient temperatures. Protective ironwood canopies minimize heat, radiation and water stress among seedlings established in their shade. In Sonoran Desert areas where open soil temperatures can reach 65 °C, the 15-degree cooler temperatures under ironwood canopies increase seedling survival rates and decrease water stress in mature plants (Suzán 1994).

Ironwood Understories as Prey Refugia

In addition to serving as a buffer from abiotic stresses (such as soil and moisture conditions), ironwood buffers nursery plants from some, but not all, biotic stresses impacting their survival and reproduction. These biotic stresses include competitive interactions among ironwoods or with other species. One ecological factor influenced by nurse plants is access of predators and herbivores to their "prey." We define "prey" broadly as any plant or animal killed by direct consumption. McAuliffe (1984*a*) demonstrated spiny, or thorny nurse plants, can reduce dramatically the amount of predation on cactus seedlings by large and small herbivores, such as ungulates, rabbits and rodents. Ironwood, with its spiny, often low-sweeping branches, provides an effective prey refugium for vulnerable seedlings intertwined within its foliage. However, because desert tortoises, rabbits, jackrabbits and packrats rest, nest or burrow under ironwoods, seedlings not fully sheltered by down-sweeping branches can suffer higher levels of predation (McAuliffe 1984*a*). Young spiny ironwoods may deter predators more effectively from young seedlings than older ironwoods, which have fewer spines in reach of grazers.

Nurse Plants Form Resource Islands of Favorable Soil Composition

> Ironwood, in the secret garden of the desert, searches the depths of the subsoil looking for precious nutrients and subterranean water. Through the years, beneath it foliage, innumerable leaves have decomposed and transformed into a thick layer of organic matter. After the rains, the dust, rich with phosphorous, nitrogen, and potassium that has accumulated on the leaves, washes off, increasing the fertility of the soil below the canopy.
>
> Alberto Burquéz, *Arbol de la Vida* (1999)

Tree legumes such as ironwood and mesquite influence the soil composition beneath their canopies in several ways (Garcia-Moya and McKell 1970). They "fix" nitrogen through forming symbiotic relationships with *Rhizobia* bacteria (Felker and Clark 1981). They also "pump" nitrogen and other nutrients up from their deepest root zones. Ironwoods incorporate these nutrients into their foliage, over time enriching topsoil composition as their fallen leaves gradually accumulate and decompose beneath their canopies.

In addition, mesquites and ironwoods in xeroriparian corridors on floodplains act as traps for the nutrient-rich organic debris carried by flashfloods (Nabhan 1993). Legumes dominate the species represented in floodwash debris, adding nitrogen to the soils beneath ironwood's drooping branches and trunks (Table 4).

Table 4: Dispersal of seeds, fruit and organic matter to ironwood habitats via flashfloods

Family	**Species**	**Reproductive**	**Vegetative**
Amaranthaceae	*Amaranthus* sp.	Seeds	-
Asteraceae	*Ambrosia deltoidea*	Seeds	Leaves
	Hymenoclea sp.	-	Leaves
	Isocoma tenuisecta	-	Leaves
Boraginaceae	Unidentified	Seeds	-
Cactaceae	*Opuntia* sp.	-	Cladodes (pads)
Fabaceae	*Acacia* sp.	-	Leaves, twigs
	Olneya tesota	-	Leaves, twigs
	Parkinsonia aculeata	-	Leaves, twigs
	Parkinsonia florida	Pods, seeds	Leaves, twigs
	Prosopis velutina	Pods, seeds	Leaves, twigs
Poaceae	Unidentified	"Seeds"	-
Ulmaceae	*Celtis reticulata*	-	Leaves, twigs
Zygophyllaceae	*Larrea tridentata*	-	Leaves, twigs

From samples taken in Topawa, Arizona washes during a summer 1981 flashflood (Nabhan 1993)

Several recent studies analyzed the influences of nurse plants on soil composition, comparing ironwood and mesquite in the southernmost reaches of the Central Gulf Coast desert scrub in Baja California (Carrillo-Garcia *et al.* 1999). In general, nurse plants with drooping branches help catch and stabilize wind-borne soil, forming mounds that function as "resource islands" for other plants. The resource islands around ironwood and mesquite trunks support high densities of symbiotic bacteria and fungi that aid in the establishment of understory plants, providing them with moisture and nutrients not available in barren interspaces. Finally, there are differences in the mycorrhizal fungi and soil composition associated with mesquite and ironwood, leading them to favor different sets of understory plants, thereby creating heterogeneity through "patch dynamics."

In particular, mature mesquites have a greater influence on increasing soil moisture availability, decreasing soil alkalinity, increasing clay content and increasing understory cactus growth rates than do immature mesquites or mature ironwoods (Carrillo-Garcia *et al.* 1999). Ironwoods tend to slightly increase alkalinity and moisture availability, hardly effect soil texture, but significantly increase root, bacteria and fungi densities. Whereas ironwood was the predominant nurse plant for the century plant (*Agave datylio*), mesquite canopies fostered the proliferation of the ashy limberbush (*Jatropha cinerea*), the dioecious fishhook cactus (*Mammillaria dioica*), and the exotic buffelgrass (*Pennisetum ciliare*).

Ancient Ironwood Forests as Wildlife Habitat

The last quarter century of desert conservation efforts brought needed attention to riparian habitats such as cottonwood-willow gallery forests found adjacent to perennial and intermittent streams, and to mesquite bosques fringing cienega wetlands. Some ironwood forests are, in essence, xeroriparian habitats within desertscrub ecosystems. Ironwood stands along ephemeral streams may influences the local ecology in ways similar to riparian forests along intermittent and perennial streams. Relatively speaking, xeroriparian habitats along ephemeral streams have received far less attention. Perhaps because they are much more extensive and less visually dramatic, xeroriparian habitats have been underrated.

In breeding bird surveys within the Sonoran Desert, Vander Wall and MacMahon (1984) determined that the mere presence of ironwood, palo verde, and acacia sub-trees increased bird species richness by 63.7% along a desert vegetation gradient around Organ Pipe Cactus National Monument. Where these leguminous nurse plants and associated columnar cacti were absent, elf owls, gilded flickers, Gila woodpeckers and curve-billed thrashers disappeared from the bird community (Vander Wall 1990). The presence of ironwoods and other legumes dramatically increased foliage height diversity, which correlated significantly with bird species diversity (Vander Wall and MacMahon 1984).

Tewksbury and Petrovich (1994) specifically state that "the influence of ironwood on large cacti may be especially important in maintaining good nest sites and foraging ranges for woodpeckers and pygmy owls, as they depend on the cacti for habitat . . ." When they compared their observed versus expected (on the basis of cover values) number of bird nests for nine one hectare plots in the Central Gulf Coast of Sonora, ironwood was the only woody perennial where they found a significantly greater than expected number of bird nests. They found twenty-seven nests in ironwoods, compared to only nineteen nests in all the other species of trees and shrubs combined. Their observations also suggest increased mammal and reptile activity as ironwood canopy size increased (Tewksbury and Petrovich 1994).

Lush riparian habitats, such as closed-canopy mesquite bosques, are often assumed to be the most threatened habitat type in this region. However, mounting evidence indicates the biodiversity associated with xeroriparian habitats has become just as imperiled. At least 31 breeding bird species declined locally in riparian mesquite bosques within the last half-century. Thirty of these birds also spend part of the year in ironwood habitats – either in mixed xeroriparian stands of acacia-mesquite-ironwood, or in ancient ironwood and cactus forests (Table 5). Preliminary evidence indicates at least 15 of these species declined since 1950 within xeroriparian habitats. However, few repeat censuses from these habitats exist.

Masked bobwhites also utilize ironwood habitats, but have not been seen this century in mesquite bosques. This preliminary survey cannot conclusively link ironwood habitat loss with declines in local species richness. Nonetheless we encourage avian ecologists to focus more on ironwood habitats since it gives us reason for concern about the health status of wildlife habitat within xeroriparian corridors overall.

A recent report by The Wildlands Project in Tucson, Arizona, recognizes ironwood's potential role as an umbrella species. The report lists ironwood as one of six possible "focal species", around which a Sonoran Desert Reserve Design proposal could be based (Turner, D.S. 1999). The 6 focal species are derived from the list compiled by 54 scientists asked by Nabhan and Holdsworth (1998) to identify potential focal species for different subregions of the Sonoran Desert.

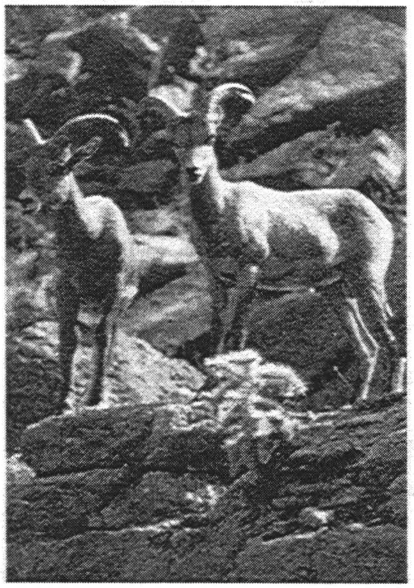


Figure 5: Desert bighorn sheep forage on ironwood leaves and pods during the heat of the summer (Arizona-Sonora Desert Museum archives).

Table 5: Breeding birds with probable population declines in legume-dominated floodplain woodlands in the Sonoran Desert: riparian mesquite bosques compared with xeroriparian ironwood-acacia-mesquite habitats, 1950 to 2000

Scientific Name	**Common Name**	**Riparian Decline (-)**	**Xeroriparian Decline (-)**
Accipiter cooperii	Cooper's Hawk	1-, 2-, 5	2-, 5
Parabuteo unicintus	Harris' Hawk	4-	4-
Buteogallus anthracinus	Black Hawk	4-, 5-	0
Buteo albonotatus	Zone-tailed Hawk	1-, 5	5
Buteo jamaicensis	Red-tailed Hawk	1-, 5	5
Buteo nitidus	Gray Hawk	4-	5
Falco sparverius	American Kestrel	2-	5
Zenaida macroura	Mourning Dove	1, 4	1, 4
Callipepla gambelii	Gambel's Quail;	1, 4	1, 4
Colinus virginianus	Northern (Masked) Bobwhite	-	5-
Zenaida asiatica	White-winged Dove	6-	6-
Columbina passerina	Ground Dove	1, 4	1, 4
Coccyzus americanus	Yellow-billed Cuckoo	1-, 2-,5	5
Bubo virginianus	Great Horned Owl	1-	1-
Otus kennicottii	Western Screech Owl	1-,5	5
Glaucidium brasilianum	Ferruginous Pygmy Owl	1-, 2-,4-	2-, 4-,5
Micrathene whitneyi	Elf Owl	1-, 4, 5	5
Ceryle alcyon	Belted Kingfisher	2-, 4	-
Melanerpes uropygialis	Gila Woodpecker	1-,5	5
Picoides scalaris	Ladder-backed Woodpecker	1-,5	5
Camptostoma imberbe	Beardless Tyrannulet	1-	-
Sayornis nigricans	Black Phoebe	1-, 2-	-
Pyrocephalus rubinus	Vermilion Flycatcher	1-, 2-5	2-,5

Myiarchus cinerascens	Ash-throated Flycatcher	1-,5	5
Myiarchus tyrannulus	Brown-crested Flycatcher	1-,2- 5	2-, 5
Stelgidopterex serripennis	Rough-winged Swallow	2-, 5	5
Hirundo pyrrhonota	Cliff Swallow	1-, 5	5-
Corvus corax	Common raven	2-	2-, 5
Auriparus flaviceps	Verdin	1-, 4	4, 5
Molothrus aeneus	Bronzed Cowbird	1+, 4+	1+. 4+
Phainopepla nitens	Phainopepla	1-, 4	4
Toxostoma crissale	Crissal Thrasher	1, 4	1, 4
Toxostoma curvirostre	Curve-billed Thrasher	1, 4	1, 4
Polioptila melanura	Black-tailed Gnatcatcher	1, 4	1, 4
Vireo bellii	Bell's Vireo	1-, 4	1-, 4
Vermivora luciae	Lucy's Warbler	2-	5
Cardinalis cardinalis	Northern Cardinal	1, 4	1, 4
Cardinalis sinuatus	Pyrrhuloxia	1, 4	1, 4
Pipilo aberti	Abert's Towhee	1, 4	1, 4
Melospiza melodia	Song Sparrow	2-, 4-	-
Icterus cucullatus	Hooded Oriole	2-	2, 5

(-) = an observed local decline is indicated by minus sign (-) following the number assigned to each literature source; numbers without a minus sign simply indicate known use of this habitat (0) indicates none present in the habitat. Sources: (1) Johnson, Bennett and Haight, n.d.; (2) Rea 1983; (3) Phillips, Marshall and Monson (1964); (4) Monson and Phillips (1981); (5) Russell and Monson (1998); Wolf (pers. comm.); Siminski (pers. comm.).

Additionally, we lack good wildlife inventories for the xeroriparian corridors which include ironwood habitats, defined here as desertscrub vegetative cover dominated by tree legumes, with a minimum of five reproductively mature ironwoods per hectare. Lacking such a definitive inventory, we sent a survey to vertebrate zoologists experienced in Sonoran Desert field studies to obtain a preliminary working list of ironwood habitat fauna (Appendix I). This list provides initial documentation that more than 64 mammal species, 149 bird species, 62 reptile and amphibian species utilize ironwood habitats as defined here. This appendix also documents the use of these habitats as roost and refuge sites (123 species), for forage (96 species), and for nesting and burrowing (113 species). With the 233 species of vascular plants found under ironwood canopies (Appendix II), these animal occurrences bring the level of ironwood-associated biodiversity up to 508 species throughout its range (this total excludes microbes and invertebrates, including insects).

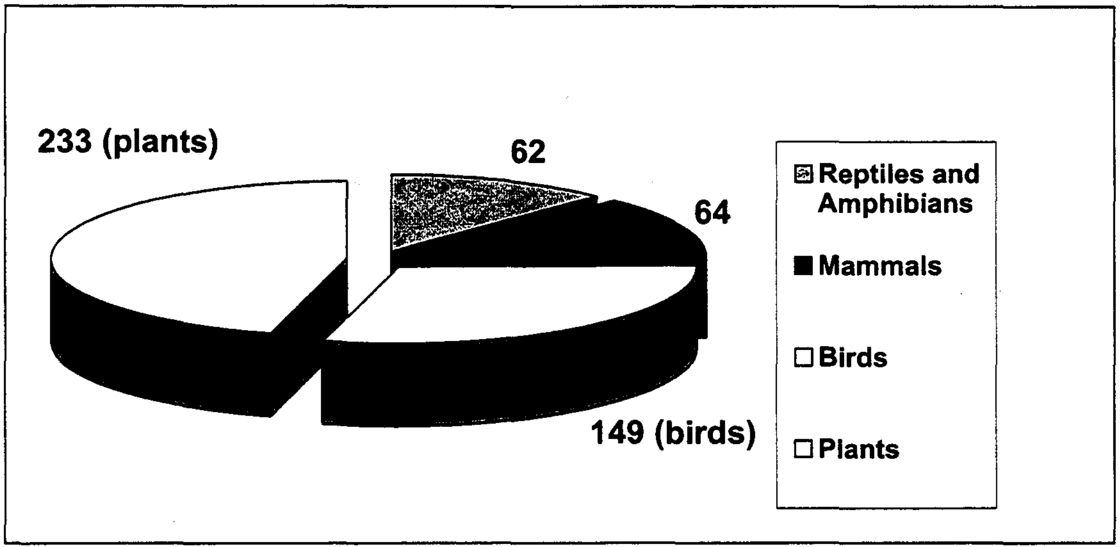


Figure 6: Proportion of species of various lifeforms associated with ironwood trees

While high, this overall level of species richness under ironwood *trees* should not be confused with the biodiversity associated with ironwood *habitat* at any particular study site or locality. Site-specific biodiversity associated with ironwood habitat has, in fact, been estimated as part of the International Biome Project studies at the Silverbell site at the northern edge of Avra Valley in Pima County, Arizona (Orians and Solbrig 1977). The IBP's team of taxonomists and ecologists found 674 species of vertebrates, invertebrates and vascular plants at the Silverbell site (Table 6). Based on relative cover and density estimates, they rated ironwoods as the second most valuable plant in terms of community importance, following triangle-leaf bursage (*Ambrosia deltoidea*) (Szarek 1979).

Table 6: Biodiversity associated with bursage-ironwood habitat,
IBP Silverbell site, Avra Valley, Pima County, Arizona.

Biological Group	**Number of Species**
Ants	25 species
Orthoptera	25 species
Bees	188 species
Anurans	12 species
Lizards	19 species
Snakes	24 species
Birds	57 species
Mammals	64 species
Vascular Plants	250 species
Total	674 species

From International Biome Project data compiled by Orians and Solbrig (1977), on file at the office of Arid Lands Studies, University of Arizona.

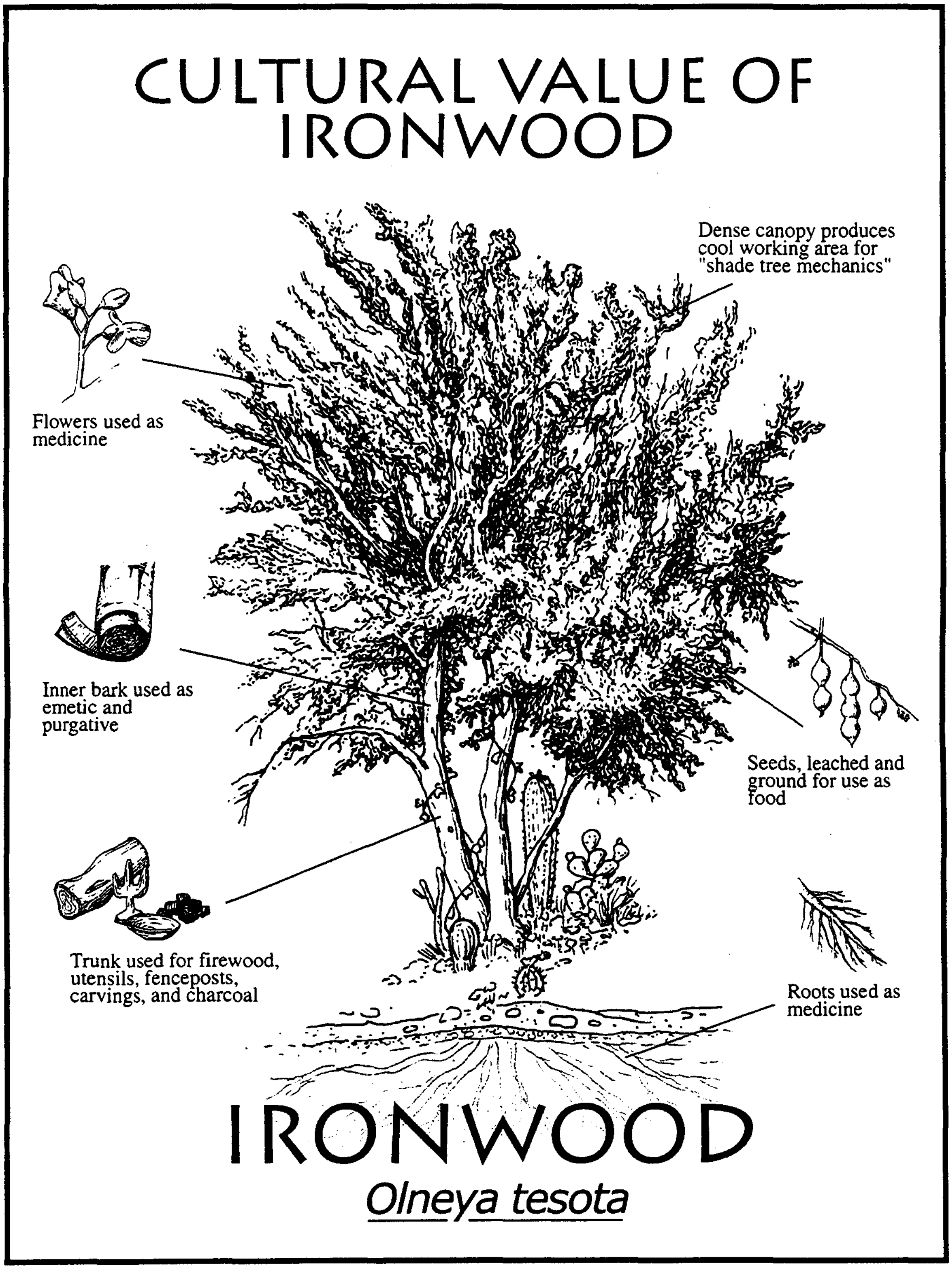


Figure 7: Cultural Value of Ironwood (courtesy of Bill Singleton, Pima County Administrative Office).

Cultural and Traditional Uses of Ironwood in the Sonoran Desert Region

The many indigenous and ethnic communities of the Sonoran Desert region have long valued ironwood as a cultural and ecological resource. In addition to the common English and Spanish names, ironwood and *palo fierro*, it is also known by many other names, some of which refer to its hard wood, to its spineyness, or to its "kinship" or "familial" relationship with other desert plants (Table 7). Many rural dwellers in México recognize its role as a "nurse plant" by referring to ironwoods as *nodrizas*, 'nursemaids', or *madrinas*, 'godmothers', which protect other plants beneath their "skirts". Highly desirable as an ornamental and shade plant in both the U.S. and México, large ironwood trees once sheltered the infamous open air "shade-tree [auto]mechanics" of the desert borderlands near border towns such as Sonoyta, Sonora.

Table 7: Common names from native tribes of the Sonoran Desert Region

Tribe	**Native Language**	**Name**	**Sources**
O'ob	Lowland Pima	Va'inum	Pennington 1980
Hia Ced O'odham, Akimel O'odham, & Tohono O'odham	Northern Piman	Ho'idkam	Nabhan 1993; Rea 1997
Yoemem (Mayo & Yaqui)	Cahitan	Ehea	Molina, Valenzuela and Shaul 1999
Comcáac	Seri	Comitin, Hesen, Comitin, Cocootij	Felger and Moser 1985
Cocopa & Mohave	Delta Yuman	K^wn^ya, 'i ·wír	Crawford 1997

In addition to its more general aesthetic and cultural values, specialized economic uses of ironwood abound. Some of the traditional uses had negligible impact on ancient ironwood forests over the centuries, since the products utilized either renewable resources such as pods, seeds and flowers, or salvaged wood from already-dead trees. Historically, woodcutters with axes and saws were seldom capable of cutting ironwood trunks so close to the ground that the trees could not resprout new branches. Since the introduction of diamond-blade chainsaws, massive ironwood trunks can be cut low enough to eliminate any possibility of regrowth. While some woodcutters have been culturally trained to "coppice," or selectively cut, rather than "clear-cut" ironwoods and mesquites, other woodcutters simply take as much legume wood as they can obtain from a particular site, and then move on. Woodcutters trained to prune or coppice in the traditional manner, now make up a smaller percentage of ironwood harvesters than ever before.

The following accounts of historic and contemporary uses focus on the traditions of the Seri (Comcáac), the Yaqui and Mayo (Yoemem), the Lowland Pima (O'ob), the

Sand Papago (Hia c-ed O'odham), the Desert Papago (Tohono O'odham), the Gila River Pima (Akimel O'odham), the Yuma (Quechan or Kw'tsan), the Cocopa (Kwapa), Mohave (Mojave), Maricopa (Opa or Pi-pa-Kwes) and the Pai (Yavapai and Paipai or Akwa'ala). These tribes have inhabited areas that overlap with ironwood habitat from the southern reaches of Sonora in the municipality of Navajoa, to the northernmost reaches north of Phoenix and Parker, Arizona. The ironwood tree has a long history of a variety of uses among these tribes.

Food Uses

The pods of the ironwood contain one to eight edible beans or legume seeds. For centuries, the native tribes of the Sonoran Desert collected and dried the ripened pods. Native people gathered the dried pods where they fell under the trees, trampled or beat the pods with sticks to free the protein-rich beans, then winnowed them in baskets (Spier 1970). The Seri, Cocopa, Sand Papago, Desert Papago, Gila River Pima, Maricopa, Yuma, Mohave and Yavapai all prepared a protein-rich flour and gruel or mush from the toasted (or parched) and ground seeds of ironwood (Castetter and Bell 1942, Spier 1970). Processing techniques undoubtedly reduced the levels of bitterness in the beans, caused by anti-nutritional factors (Table 2), making them more palatable and digestible. For example, after beating the pods with sticks, the Yuman tribes leached the bitterness from the seeds much as California tribes leached acorns. They soaked the seeds, or the resulting ground meal, in a hole on a sandy river bank for as much as two to three days, then boiled them several times to remove the bitter taste (Spier 1970).

A solitary skilled overseer, called "the woman with dry hands", managed the leaching process at the riverbank, repeatedly pouring water over the meal until all bitter foam washed away (Spier 1970). When the liquid finally cleared, the women ground the leached seeds as finely as possible on a *metate* and made the meal into cakes or loaves (Gifford and Lowie1932). These were sometimes baked in hot ashes, further reducing the heat sensitive bitter chemicals. During baking such "ash breads" often gain minerals which increase the availability of amino acids or vitamins. The cakes were eaten dry. In the case of the Mohave, the whole seeds were stored for winter use, then leached and ground just prior to consumption (Ebeling 1986).

The Seri, who often eat the seeds whole and toasted, say the cooked seeds taste like peanut butter. The Seri reduced their own energy expenditure collecting ironwood seeds by raiding the caches of ironwood seeds stored by packrats (*Neotoma* spp.) in their nests, called middens (Felger and Moser 1976, 1985, Nabhan and Holdsworth 1998). This "energetic short circuit" — borrowing from an animal's caloric bank account rather than consuming the calories of the animal itself — is still practiced by the Seri today, as it was historically done by the Papago, Yaqui and other tribes (Figure 8).

Figure 8: Seri women unearthing packrat midden for its legume pods in Aravaipa Valley, Sonora (Chris Keith photo, 1995, courtesy of *Natural History* magazine)

Medicinal and Curative Uses

The flowers, leaves, bark, inner bark, and roots of ironwood continue to be used as traditional medicines within the region. Sonoran Desert tribes treat a variety of maladies with the preparations derived from ironwood described below. Although ironwood remains a popular remedy in many localities, it appears not to have been marketed by commercial herb vendors in the region on any frequent basis (Ford 1982). We share the following information to highlight the importance of conserving ironwood in its ecological *and* cultural habitat. The cultural property rights of indigenous communities to these medicines should be respected, and no commercial use should be made of this traditional knowledge without their prior consent.

Mouth and gum infections- The Yaqui grind ironwood roots into a paste to cure mouth and gum infections. Seri herbalists reserve the use of ironwood for more serious infections. Cuttings of the bark are boiled and administered as a tea and poultice to their patients (López 1998; M. Monroy, pers. comm., August 1999).

Respiratory symptoms- The Yaqui and Seri make a tea from crushed leaves of the ironwood to alleviate asthma and clear mucous from the lungs (López 1998; Felger and Moser 1985; G. Herrera, pers. comm., March 1999).

Gastrointestinal problems- The Mayo steep the bark for a tea to treat diarrhea. The Seri will drink this preparation as an emetic to induce vomiting. The Yaqui use the same preparation to relieve stomachaches and *empacho*, a stomach-related Mexican folk illness (López 1998, Felger and Moser 1985).

Kidney and blood circulation- The Sand Papago make a tea from the flower of the tree to cure kidney stones and strengthen blood circulation. As recently as 1990, a Mexican Papago herbalist allegedly cured a Puerto Peñasco woman suffering from a kidney ailment (Nabhan, field notes). The Seri drink a tea made from the inner reddish bark fibers, to cleanse and detoxify their blood for strength during long-distance runs or battles (López 1998; G. Herrera, pers. comm., March 1999).

Ceremonial and Ritual Uses

The Mayo make rosary beads and crosses from the wood of the ironwood (López 1998). The Gila River Pima make music on an ironwood rasping stick to avert evil or bring rain (Rea 1997). During the flood episode of the Gila River Pima Creation Epic, the daughter of a powerful shaman uses an artificial phallus fashioned from ironwood to impregnate the legendary "Handsome Man", who had been ravaging all the young women of marriageable age. Relatives bury ironwood seeds with deceased Pima elders to nourish them on their journey to the next world (Rea 1997). Young Seri men drink the ironwood "essence," a purification and emetic tea brewed of ironwood heartwood, to give

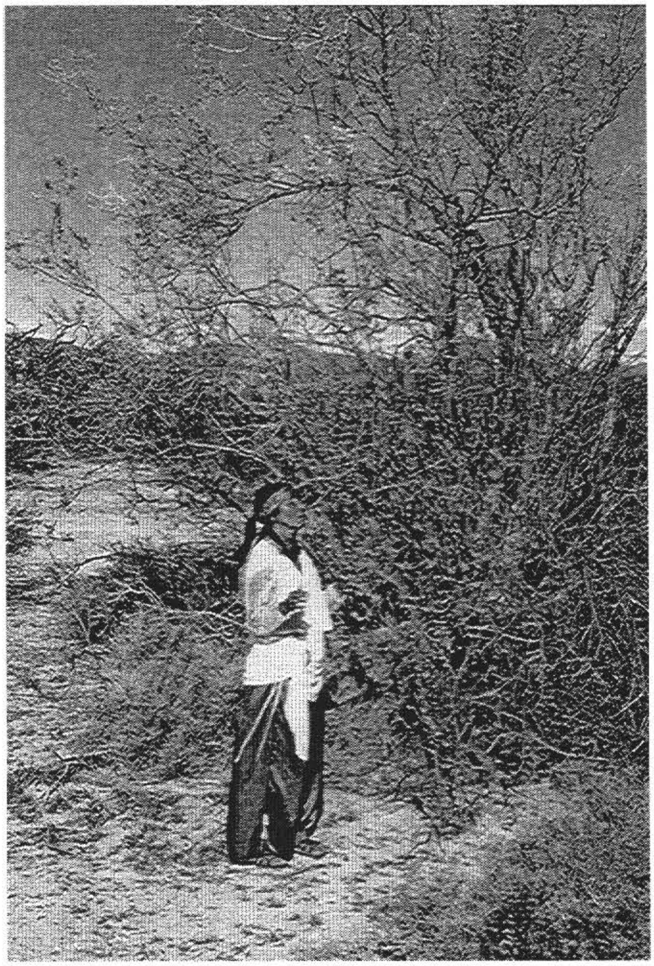


Figure 9: The daughter of the first Seri carver of ironwood figurines returns to the very tree from which her father, Jose Astorga, initially harvested wood more than 30 years before. Although the tree grows along a roadside within a few kilometers of Desemboque, the Seri craftsmen there have not cut it down. Their sustainable harvesting has been documented in the surrounding area as well, where only dead branches have been pruned from live trees, causing no permanent damage to the trees (Big Jim Griffith, 1998 photo).

them courage, strength and endurance for long runs to obtain water, to fight or to hunt (G. Herrera, pers. comm., March 1999). Seri shamans tie bullroarers, shaped from flat, propeller-like pieces of ironwood, on each end of a cord and twirl them to summon the spirits (Figure 10). They also made a tea from the green wood of the ironwood for use in their vision-quest ceremony (Felger and Moser 1985).

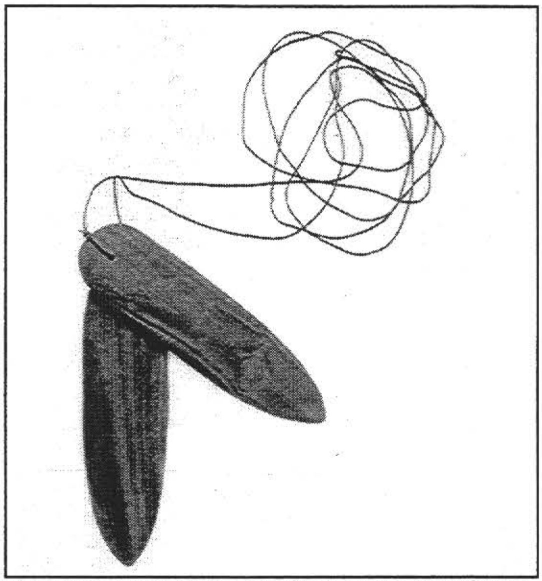


Figure 10: A Seri Indian set of bullroarers made by the late Miguel Barnett Astorga from ironwood branches. Seri medicine men sound bullroarers as they enter spirit caves (David Burckhalter photo, 1999, courtesy of Gary Nabhan and the University of California Press).

Musical Instruments

The Seri, Mayo, Yaqui, and Gila River Pima all create musical instruments from ironwood. They carve ironwood rasps and small tambourine rattles from ironwood to accompany singing and dancing during ceremonies and dances (López 1998, Rea 1997). The Seri sometimes make their violin bows from ironwood (Felger and Moser 1985).

Household Uses

All of the native communities in the Sonoran Desert region, except the nomadic Seri, tended to build their permanent dwellings in the shade of ironwood trees. Many adobe, mud-and-dabble or ocotillo-frame houses sprang up under or near the shade of an ironwood tree. Fences constructed to mark property and contain animals were sometimes made from ironwood branches. Posts and beams of ironwood were used as the upright posts and horizontal crossbars or *vigas* in many houses. The Lowland Pima in México have used ironwood to make household utensils, such as bowls and spoons (Pennington 1980, López 1998).

Tools and Agricultural Implements

Because of its extremely hard wood, the ironwood tree served as a substitute for metal and stone for native peoples in the Sonoran Desert. The Gila River Pima and Desert Papago made three agricultural tools from the ironwood heartwood-- the digging stick, the planting stick and the weeding hoe. To make a straight digging stick, the earliest agricultural implement, the Gila River Pima peeled the bark and the sapwood from two sides of the digging end of the stick. Once they exposed the heartwood, the Gila River Pima honed the blade with a stone to produce a sharp, chisel-like edge. The blade of the weeding hoe looked like that of a machete, about three inches wide and as long as a man's forearm. Using this ironwood hoe, the farmer loosened the soil and cut away the roots of weeds (Rea 1997).

In the Spanish Colonial Period, a rudimentary plow, known as a *gi:ki*, was sometimes made from ironwood by the Desert Papago and Gila River Pima. The Desert Papago and Sand Papago used knives and sickles made from ironwood to harvest wheat (Castetter and Bell 1942). From the green, or lighter wood, the Seri crafted a meat rack and carrying yoke. They used the dark wood to make grinding pestles, a pry bar to harvest agave hearts, and double bladed boat paddles (Felger and Moser 1985).

Weapons

The Gila River Pima used a heavy club made from mesquite or ironwood to defend their families against Apache attacks. These "potato masher" style clubs weighed about two pounds (Rea 1997). The Seri historically crafted harpoon points from ironwood, which they used to hunt sea turtles (Figure 11). Today they still make ironwood harpoon points to sell to tourists.

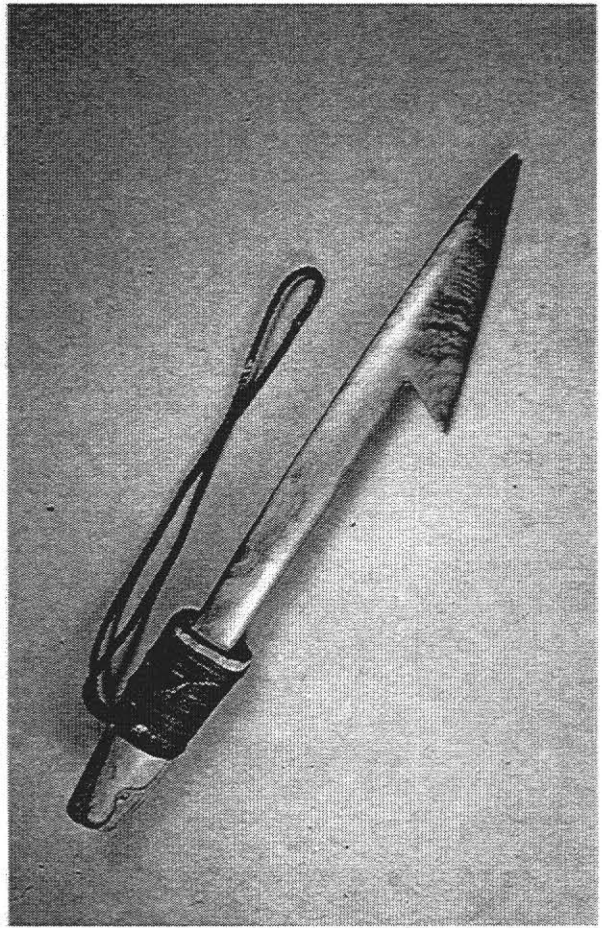


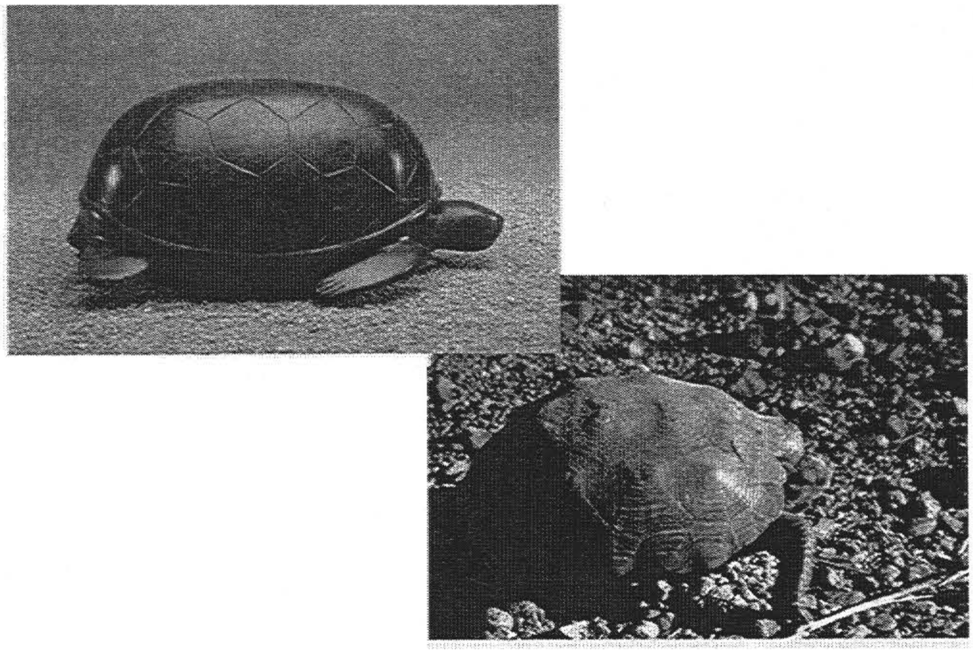
Figure 11: A harpoon point carved of ironwood by Seri Indian sea turtle hunter Guadalupe López Blanco of Desemboque, Sonora (David Burckhalter photo 1999, courtesy of Gary Nabhan).

Crafts

> For visitors to Sonora, México, ironwood carvings are as prominent a part of the scene as saguaro cacti and taco stands. The wooden figurines are carved by two sets of people—the Seri Indians and rural Mexicans living in Bahía Kino, Sonora—and are now sold in roadside stands, marketplaces, and craftshops from Alaska through Arizona, to central México.
>
> Sara St. Antoine, Ironwood and Art: Lessons in Cultural Ecology (1994)

In the late1950's, Jose Astorga Encinas of the Seri fashioned the first innovative carvings made from ironwood (Ryerson 1975). He and other Seri artisans developed ironwood carvings into a successful tourist arts business to bring needed cash to their rapidly changing economy. Seri carvers soon gained international recognition for their elegant representations of birds, marine mammals and reptiles, and the remarkable way that their carvings capture the animals' subtleties of movement and behavior. By the 1970's, non-Indian craftsmen began to emulate Seri carvings and sell their own ironwood figurines in Sonoran beach towns. During the 1980's, Mexican carvers, using chainsaws, sanders and lathes to mass-produce imitations of indigenous carvings, largely usurped the Seri in their own niche industry. U.S. tourists are the primary market for these carvings (Felger and Moser 1985, St. Antoine 1994).

Figure 12: Carved ironwood desert tortoise (photo by Helga Telwes, 1998).
Figure 13: Living desert tortoise (photo courtesy of Arizona-Sonora Desert Museum archives).



The sale of ironwood carvings to tourists once generated hundreds of thousands of dollars a year for the Seri and also provided employment for the 2000 to 3000 Mexican families involved in carving in northwestern Sonora (Ryerson 1975). The economic value of the carvings was especially important during the depression of the Mexican economy in the 1980's. Regrettably, despite their creative and entrepreneurial contribution to the economy of the region, the Seri have yet to gain substantive recognition or long-term benefits for beginning the ironwood carving industry in México (Mellado 1985; St. Antoine 1994).

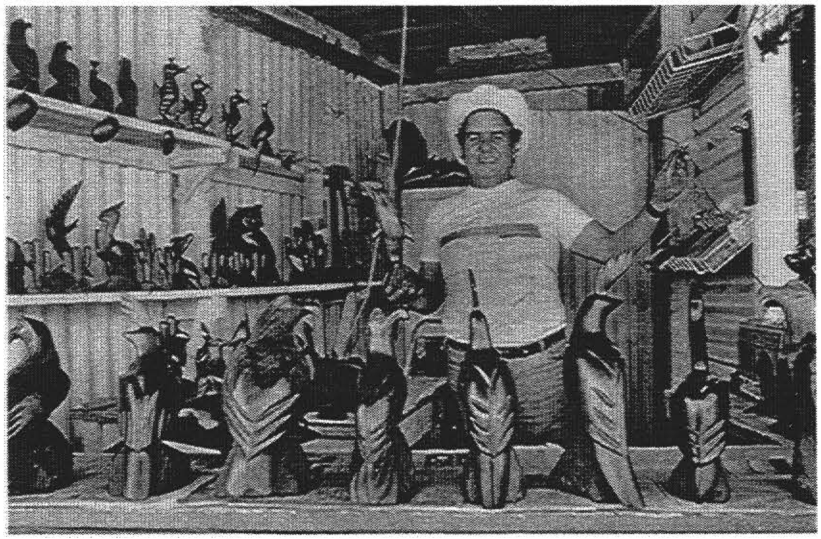


Figure 14: Ironwood animal figurines mass-produced by machines are carved and sold by non-Indians in a shop in Bahía de Kino, Sonora (David Burckhalter 1993 photo, courtesy of Conservation International).

Machine-assisted ironwood carving workshops operate in four municipalities in Sonora and in several Baja California municipalities (Table 8). In 1995, the greatest number of ironwood workshops in a single locality was in the town of Miguel Alemán/Calle 12 (57), followed by the city of Hermosillo (53), and the beach town of Bahía de Kino (38). The Sonoran workshops use as much as 2,544 metric tons (m.t.) of wood per year, only 7% of which permitees cut legally (Paredes and López 1995). Official permits have been issued for the collection of 182 m.t. of dead wood per year, at most (Paredes and López 1995). Since 1990, the cutting sites shifted from the coastal region to sites further inland and to higher elevations as the supply of wood in the Central Gulf Coast dwindled (H. Suzán, pers. comm., March 1999).

Table 8: Number of active workshops[1] producing ironwood carvings in México 1999-2000

Number of Workshops	Locality	Municipality
1	El Gulfo de Santa Clara	P. Elias Calles
3	Sonoyta	P. Elias Calles
6	Bahía de la Cholla	Pto. Peñasco
4	Desemboque del Sur	Pitiquito
7	Punta Chueca	Hermosillo
38	Kino Viejo	Hermosillo
57	Miguel Alemán/Calle 12	Hermosillo
53	Colonia Palo Verde and Villa de los Seris	Hermosillo
4	Magdalena de Kino	Magdalena
*	Bahía San Carlos	Guaymas
*	Mexicali	Mexicali
*	Ensenada	Ensenada
*	La Paz	La Paz
162-177	Total number of workshops in Sonora and Baja California	

1 Workshops, as defined here, have three or more artisans working cooperatively on different stages of the same carving. While 180 Seri once made ironwood carvings, only 18 rely on woodcarving as their main source of income today. Another 2000 Sonorans and 25-50 Baja Californians reportedly carve ironwood.

* Areas where workshops occur, but the number of workshops has not been documented.

In 1991, the Seri began stricter vigilance to protect their own ironwood populations, and requested assistance from biologists to document the damage done by clandestine woodcutters to the resource in their territory. In 1994, as another means to slow ironwood depletion, the Seri started carving soft stone, obtained from the rocky ridges of the coast. With hand tools, they now shape stone into the same smooth shapes of sea turtles, crabs, dolphins and birds, as they once shaped ironwood.

Hundreds of internet sites contain information about ironwood. Several websites sell carvings made of ironwood, including ones made by competitors of the Seri. However, other sites are dedicated to the preservation of ironwoods. The potential of this media to convey the message of ironwood depletion worldwide needs to be tapped as the global market continues to grow.

Fuel for Cooking

Ironwood burns extremely hot and makes excellent fuel. Most indigenous communities with access to it use ironwood as fuel when pit-roasting food plants such as agave hearts and cholla buds. Before European settlement, roasted agave hearts were widely eaten throughout the Sonoran region. Throughout the Hohokam region, villagers dug large communal roasting pits to cook the agave (Fish and Fish 1992). The Seri burn ironwood branches exclusively to obtain the degree of heat necessary to pit-bake agave for their communal feasts (R. Moreno, pers. comm., August 1999).

> Ironwood, as the name says, is an exceedingly hard and heavy wood. The core of it will blunt the edge of an ax or saw, and a solid chunk will sink in water. Yet the wood when dead is very brittle and breaks easily against a rock or another ironwood branch. As fuel, especially for campfire cooking, it is unexcelled, burning slowly, smokelessly and very hot. There is no better way to broil a piece of meat than by laying it directly upon a bed of ironwood coals. South of the border in the state of Sonora, ironwood is much in demand as a household fuel and may soon disappear from the Mexican deserts. Year by year the professional woodcutters fan out ever farther across the land, hacking and hewing to supply the needs of the rapidly growing population. They too wish to eat, live and multiply, these woodcutters, and so the ironwood and after it the mesquite will have to go. México is already in the swarming stage, that busy time that precedes destruction.
>
> Edward Abbey, *Cactus Country* (1973)

Charcoal Production

Mexican charcoal production for export to the U.S. increased more than twenty-fold in the last thirty years, and producers derive no less than 15% of this exported charcoal from relatively slow growing legumes from the Sonoran Desert. Economic, social and political forces in México and the U.S. all contributed to this increase. Responding to American consumers' appetite for mesquite-smoked meats in the early 1980's, Sonora alone produced 180,000 metric tons of charcoal made from mesquite and other legumes between 1983 and 1992. México's average annual charcoal production rose from 2,619 metric tons (m.t.) in 1976 to a high of 28,144 m.t in 1988, and averaged 17,965 m.t. between 1983 and 1992 tree (Solís-Garza and Espericueta 1997).

Official figures indicate mesquite charcoal exports from Sonora declined after 1988, and in Sonora the government gave out cutting permits for only 118,000 kg of ironwood in 1997. However, most observers agree desertscrub habitats containing a mix of mesquite and ironwood continue to be exploited for charcoal at a significant level. In Sonora, as in Baja California, the majority of trees cut for charcoal consist of several species of mesquite (*Prosopis* spp.). However, ironwood occurs in many of the municipios where mesquite woodcutting is officially listed on permits, and its wood is probably counted among the volumes of mesquite recorded for the municipios of Altar, Carbo, Plutarco Elias Calles, Hermosillo, Pitiquito and Trincheras, which collectively reported 4,100,000 kg. of legume wood cut in 1997 (INEGI 1998).

Solís-Garza estimates 54% of all woodcutting permits granted in Sonora are given for charcoal-making, which requires five tons of wood for every ton of charcoal produced. Producers throw ironwood into charcoal ovens along with mesquite because it makes a heavier product per volume, and does not pulverize into "coal dust" as easily. Our spot-checks of mesquite charcoal bags from Sonora in the early 1990's indicated ironwood comprised from 10 to 40% of the exported volume at that time.

Figure 15: Charcoal making near Benjamin Hill, Sonora, where both ironwood and mesquite were cut. Trains then carried the charcoal bags to consumers in northern California (David Burckhalter 1994 photo, courtesy of Gary Nabhan and Conservation International).

Even when permitees or buyers ask that ironwood be excluded, poorly-paid woodcutters are inclined to add available ironwood to mesquite simply to increase the weight of each charcoal bag produced, for they are paid by the kilo. In contrast to the carvers' preferred use of already-dead ironwood, charcoal makers will often cinch the bark or cut green wood, thereby destroying an entire live tree (Solís-Garza and Espericueta 1997, Paredes and López 1995).

Charcoal production in Sonora began on a large scale in 1958 in the Yaqui Valley, supported entirely with North American capital. During the 1960's, charcoal production passed into the hands of Mexican-owned export companies. In 1975, when diamond-bladed chainsaws came into use, trunks could be trimmed back closer to the ground where resprouting is less probable (Rosas 1998).

Figure 16: Charcoal making pit with ironwood logs being unloaded by a migrant worker (David Burckhalter 1994 photo).

By 1982, while the Mexican economy was suffering, the U. S. Environmental Protection Agency closed down nearly all charcoal-making operations north of the border that released significant quantities of wood smoke and other pollutants into the air. Perhaps because of these conditions, the two countries liberalized charcoal import/export trade laws. While charcoal production in earthen pits is never too energetically efficient, the greater availability of chainsaws and off-road vehicles saved time, offsetting the production costs. Charcoal export volumes suddenly increased, and charcoal prices dropped dramatically to a low of 7.5 cents per pound in 1985, half the 1982 price. Export markets for Sonoran mesquite charcoal eventually grew from just the Tucson and Phoenix area to the entire states of California and Arizona (Rosas 1998).

In 1993, Mark Plotkin and Gary Nabhan, of Conservation International, organized the regional work-group, the Ironwood Alliance. The Alliance confirmed that a major West Coast U.S. company sourced mesquite charcoal from ironwood habitat. The Ironwood Alliance began to alert restaurants to the environmental damage done by charcoal makers, and the resulting publicity in the *San Francisco Examiner*, *Time*, *Newsweek* and elsewhere, reduced mesquite charcoal consumption in northern California. Conservation activists in the Ironwood Alliance then contacted the company and persuaded it to stop sourcing charcoal from areas still containing ironwood (G. P. Nabhan, pers. comm., August 1999). The company has since changed many of its sourcing policies and become a model for other operations.

Table 9: Charcoal Production Zones within the Range of Ironwood in Sonora and Baja California Sur, 1990-2000.

Simultaneously-active charcoal pits	Number of charcoal-producing teams of people	Municipality
207	12	Pitiquito
32	3	Caborca
18	2	Santa Ana
39	3	Tricheras
18	2	Benjamin Hill
236	7	Carbo
11	3	Villa Pesquiera
116	8	Opodepe
38	4	Hermosillo
4	1	Mazatan
11	1	La Colorada
10	1	Guaymas

Seventy five percent of the production of charcoal in Sonora occurs in the municipalities of Hermosillo, Pitiquito, Guaymas and Caborca (Table 9). Other major charcoal production sites within ironwood's range include Carbo, Benjamin Hill and Opodepe. Many sites continue to operate illegally for lack of an adequate budget that allows the Procuraduria Federal de Protección al Ambiente (PROFEPA) to accomplish needed vigilance. Solís-Garza and Espericueta (1997) visited 13 sites in Hermosillo, Pitiquito and Caborca. At these sites, ironwood ranked second to mesquite in terms of former dominance, but 34.8% of all ironwood trunks were cut compared to 28.2% of all mesquite trunks. Ironwood generally failed to resprout even where mesquite was able to do so; 23% of all legume trees left on the site were dead from over-harvesting. At the 80 sites sampled, they documented no new seedlings of one meter or less in height for either ironwood or mesquite. On sites that only permitted mesquite woodcutting, 38% of the ironwood trees sustained significant damage to their trunks or to branches larger than 10-cm. diameter. Without factoring in other threats, woodcutting alone reduced ironwood's dominance of vegetation in the four areas studied, by an average of 16.6%. Even the roots of dead ironwoods were being dug up and converted to charcoal.

Without economic incentives to do so, prospects are low for convincing charcoal industry woodcutters to keep ironwood trees intact. Many of the workers who now produce charcoal in Sonora emigrated from the adjacent states of Sinaloa and Chihuahua for lack of other economic opportunities, often leaving their families behind. These migrants live and work in crowded, makeshift camps, under conditions associated with extreme poverty. They suffer from numerous physical and social ills, alienated from nearby communities (Rosas 1998).

Other Impacts on Ironwood Abundance

Grazing

While livestock production in Sonora, México is the most important economic activity in that state, cattle overstocking rates there greatly exceed the carrying capacity of native and introduced forages. Sonora as a state averages 60% overstocking relative to carrying capacity, and in some desertscrub areas, 400% overstocking has occurred in recent years (Aguirre-Murrieta 1994). Range managers consider much of the desertscrub vegetation where ironwood occurs in Sonora, Baja California and the Papago Reservation of Arizona, to be overgrazed by present management regimes. For instance, in a sampling of 167 Sonoran range units in the early 1990's, only 15 % of these pastures had their original cover intact, whereas 37% had suffered moderate to severe invasions of undesirable species (Aguirre-Murrieta 1994). More than three-quarters of the 813,000 ha. of rangelands inventoried demonstrated poor to barely passable conditions due to sub-standard management practices. Ironwood averaged only 6.6 % cover in all rangeland sample plots occurring within the buffelgrass planting zone of Sonora (see below), but provided an average cover of 16.8% in those pastures where natural vegetation was still considered intact. Suzán (1994) confirmed that overgrazing could disrupt the periodic recruitment of seedlings necessary to sustain ironwood communities.

Competition from Invasive Species Such as Buffelgrass

Buffelgrass (*Pennisetum ciliare* L.), a subtropical perennial grass native to southern and eastern Africa, has become a major invader of and competitor in ironwood habitats. The USDA Soil Conservation Service first introduced this fire-tolerant grass into Texas in the 1940's for erosion control. It was evaluated at that time for its forage value. Mexican range managers trained in Texas then introduced buffelgrass into Sonora in 1957 as a drought-hardy forage grass for livestock pasturage (Búrquez *et al.* 1999). Cattleman's associations in México adopted it eagerly and by 1991 had intentionally planted more than 1.4 million hectares of Mexican rangelands with buffelgrass. Over a fourth of those plantings occurred within the Sonoran Desert region (Sauceda-Monarque 1996). By the mid-1990's, government subsidies for land clearing helped establish buffelgrass pastures on 500,000 to 600,000 hectares in Sonora, within 51 of the 70 municipios in the state (Paredes and López 1995, Aguirre-Murrieta 1994). Búrquez *et al.* (1999) conservatively estimate that ranchers illegally converted another 600,000 hectares in Sonora to buffelgrass pastures without government permits, and that the grass invaded 10,000s of hectares more via accidental seed dispersal along highways. Government range managers also introduced buffelgrass into Baja California Sur and Arizona in experimental plantings, from which it escaped and naturalized over a much larger area. It even naturalized in ironwood habitat at Campo Caracol in the heart of Tiburón Island, and on several other small islands in the Gulf of California (West and Nabhan in press).

This highly invasive grass generates several kinds of negative impacts on the structure and function of native plant communities where ironwood occurs. It decreases plant species richness, diversity, standing biomass, and average height of vegetation, while fire frequencies and release of carbon increase (Sauceda-Monarque 1996, Búrquez *et al.* 1999). Paired sampling of neighboring plots in Sonora of planted buffelgrass pastures and relatively-undisturbed desertscrub, show buffelgrass establishment leads to a fourfold drop in plant species richness, a tenfold drop in species diversity, and a loss of two vertical strata of vegetation (Búrquez *et al* 1994). Whereas intact desertscrub still maintained aboveground standing biomass of 5-20 Mg (Megagrams)/ha, buffelgrass pastures averaged only a third to a fourth as much biomass, from 1-4 Mg/ha (Búrquez and Martinez-Yrzar, unpublished). Sauceda-Monarque 's (1996) analysis of buffelgrass invasion on ironwood habitat in central Sonora confirmed that the presence of buffelgrass negatively affects vegetation height, species richness, and growth form heterogeneity.

Wildfires thrive where buffelgrass exists. Búrquez *et al.* (1995) suggested that nearly every buffelgrass pasture of several years in age has probably experienced at least one wildfire. In 1995 more than 500 such fires occurred in Sonoran rangelands below 1000 m. in elevation, even though wildfires are historically rare in desertscrub vegetation at these elevations. Highly combustible biomass provides fuel for fires that completely destroy ironwood and other arborescent and perennial plants in these communities, replacing them with pasture (Búrquez and Quintana 1994). Wildfires moving through buffelgrass burn hot enough to kill most legume and cactus seedlings and saplings one m. or less in height (Nabhan unpublished data). The effects of buffelgrass fires on wildlife in ironwood habitat remain generally unknown, although Esque (in press) has suggested negative effects on desert tortoises.

Because of buffelgrass' spread into some of the larger protected areas of the region where ironwood occurs, Warren (1996) proposed that buffelgrass, rather than wood-cutting, loomed as the most pervasive and severe threat long-term threat to ironwood habitats and the rare plants within them. At the time of Warren's comments, however, no one could confirm this hypothesis because buffelgrass was not yet present in existing study plots of rare plants within northern ironwood habitats (Nabhan 1996). Although few of our own permanent study plots in ironwood habitat have been invaded by buffelgrass, Búrquez and Quintana (1994) confirmed that this threat is real in central Sonora. Many Mexican and U.S. research institutions now consider introduction of buffelgrass to be the principle threat to ironwood habitat on both sides of the border. These institutions include UNAM, the University of Arizona, the University of Colorado (Búrquez *et al.* 1999), IMADES/Sonora (Paredes and López 1995); the University of Sonora/DICTUS (Solís-Garza and Vasquez del Castillo 1994) and the Arizona-Sonora Desert Museum (Nabhan 1996).

Recreational Impacts

As populations in urban areas of the Sonoran Desert increase, so do the recreational impacts on the surrounding desert areas. Even in some recreational areas remote from these urban areas, the increase in visitation and subsequent impact can be seen (Nabhan and Holdsworth 1998). The flat, open xeroriparian areas favored by ironwood are also ideal areas for hiking and off-road vehicle (ORV) use. Studies show these uses destroy surrounding plant-life. Some ORV users make illegal roads by cutting the vegetation (T. Taylor, Ironwood Alliance, December 27, 1999), and illegal wood collection is common in areas adjacent to campsites and picnic areas.

Habitat Fragmentation Caused by Agricultural and Commercial Clearing

In Mexico, the dominant threat to ironwood habitat is the conversion of lands for agricultural uses, mainly grazing, and the subsequent planting of invasive species such as buffelgrass (see Grazing and Competition from Invasive Species sections, above). The biggest threat to ironwood habitat in the U.S. is land clearing for suburban development (Nabhan and Holdsworth 1998, Ironwood Alliance Meeting, 1999). Although builders are encouraged to salvage ironwood trees and other native plants, they salvage very few (see Legal Protection).

In areas such as northern Avra Valley near Saguaro National Park, habitat fragmentation since 1970 has not only reduced ironwood densities, but also reduced pollination and fruit set of several rare plants associated with ironwood. (Nabhan, field notes, 1985).

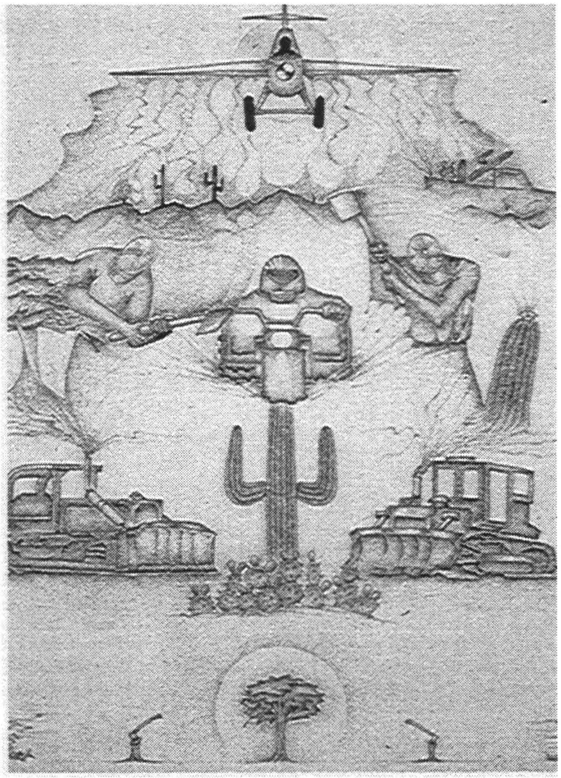


Figure 17: Land uses that affect ironwood habitat, drawn by Pima Indian (Akimel O'odham) artist-activist, Adrian Hendricks, as observed on the Gila River Indian Reservation (A. Hendricks drawing 1990 in possession of Gary Nabhan).

In a recent GIS analysis by Western States Surveying, Jeff G. Kreamer (pers. comm.), determined that the most impacted ironwood habitat in Pima County lies in northwest Tucson, south of the state land in the area designated Critical Habitat Units 3:4 by the U.S. Fish and Wildlife Service. If Kreamer's projections bear out, 9,700 acres of the 20,500 acres of ironwood habitat will be lost due to currently proposed or already-developed high-density housing. In just one 55 acre high-density subdivision which recently fragmented habitats in that area, 825 ironwoods and 110 saguaros were impacted (J. G. Kreamer, pers. comm.)

The limited available data on the impacts of suburban growth on ironwood habitats and the lack of GIS vegetation maps specifically for ironwood habitat demonstrate the need for further study and documentation, particularly in areas experiencing rapid growth such as Pima County. Actions such as the Pima County Board of Supervisors' recent resolution opposing mining in the Silverbell Mountain/ Ragged Top area show an increased awareness of the importance of ironwood habitat. The February 8, 2000 resolution listed the "sensitive wildlife habitat [of] saguaro/ ironwood/palo verde forest" as a reason for opposing the sand and gravel mine (Pima County Board of Supervisors 2000).

Fuel and Industrial Uses

In residential areas where fuelwood is scarce, cutting of ironwood has been documented from many areas. Even Organ Pipe Cactus National Monument suffers from theft of ironwood, in the area just north of the border, because of depleted fuel supplies in the northern México. Over 75% of families in the area depend on illegally harvested wood for heating and cooking purposes (Suzán et al. 1999).

The tile and brick making industries, which sell primarily to U.S. customers, harvest even more ironwood than do residential users. The firing temperature for these clay items is much higher than the temperatures needed in residential use, making ironwood the preferred fuel. Tile makers in Querobabi, Sonora consume several tons of local fluid (mixed mesquite and ironwood) per week.

Legal Protection

Legal Protection in México

The Mexican government regulates ironwood protection and under a variety of laws and regulations. Since the first documentation of its use on a commercial scale in 1942, ironwood extraction has come under regulation by México's Ley Forestal (Forestry Regulations) of 1926, revised in 1934 (Sánchez Camero 1998). However, the government did not mandate assessment of the ecological impacts of ironwood extraction until the passing of the new Ley Forestal on May 30, 1986, and its augmentation by the Ley General de Equilibrio Ecológico in 1988. These laws led to tighter restrictions, first published in México's Diario Oficial on December 22, 1993, regarding the permitting, transporting and exporting fuelwood and charcoal.

Under the jurisdiction given to it by these laws, and as a result of concerns expressed by M. S. Gilberto Solís-Garza and other members of the Ironwood Alliance, the Sonoran office of Secretaría de Agricultura y Recursos Hidráulicos (SARH) signed a 1992 agreement with the state of Sonora to better protect ironwood as a forestry resource (Sánchez Camero 1998). This agreement officially prohibited harvest of ironwood for charcoal production and clear-cutting of ironwood in government-subsidized plantings of buffelgrass pastures. In addition, the Secretaría de Medio Ambiente, Recursos Naturales y Pesca (SEMARNAP) began to restrict harvesting permits for the use of ironwood in arts and crafts. From 1992 on, SEMARNAP intended to give these permits only to those persons who could demonstrate no damage to the resource. The agreement called for greater monitoring of fuelwood use and ironwood regeneration in buffelgrass pastures, but these latter goals have been difficult to achieve.

Despite these efforts, the Instituto Nacional de Ecologia (INE), under the direction of Exequiel Escurra, regarded these actions as insufficient to safeguard ironwood's role as a keystone species. Ironwood was therefore given "special protection status" on May 16, 1994 under México's NOM-059-ECOL-1994, because of its dwindling populations' vulnerability to charcoal production, woodcrafts fabrication, and vegetation clearing for pasture planting of livestock forage (SEMARNAP 1997). The Instituto Nacional de Ecología now considers ironwood to be among its 21 priority species for conservation and restoration, along with pronghorn antelope (*Antilocapra americana*), bighorn sheep (*Ovis canadensis*), agaves (*Agave* spp.), boojums (*Fouquieria columnaris*), and cacti (many genera), which may co-occur in the same habitats as ironwood (SEMARNAP 1997). Because of ironwood's designation as a priority species for recovery, INE proposed the following actions to ensure recovery of ironwood habitats in Mexico:

1. Establish a Technical Advisory Committee of ironwood specialists;
2. Use funds from the National Trust for Wildlife (FNVS) to support ironwood habitat restoration;
3. Survey ironwood habitat's current status and identify opportunities for conservation and sustainable use;
4. Initiate reforestation of ironwood in selected areas;
5. Promote establishment of formal Units of Management and Use (UMAs) in Baja California, Baja California Sur, and Sonora, each with a management plan and monitoring strategy;
6. Develop options in the area of craft usage of ironwood by introducing other, less threatened hardwoods to carvers (an action which the Comisión Nacional para el Conocimiento y Uso de la Biodiversidad (CONABIO) already initiated);
7. Elaborate an action plan for ironwood conservation and use with state representatives of SEMARNAP, the Seri tribe, and Instituto del Medio Ambiente y el Desarollo Sustentable del Estado de Sonora (IMADES/Sonora);
8. Strengthen vigilance and site monitoring through Procuraduria Federal de Protección al Ambiente (PROFEPA) forestry wardens and their collaborators; and
9. Designate extraction-free "sanctuaries" for ironwood in Sonora and both states of Baja California.

Since the drafting of these recommendations, Barbara Torres of SEMARNAP's Sustainable Use of Wildlife division in México City, began elaborating a comprehensive plan for ironwood recuperation and sustainable use through consultations with biological experts and the Seri tribe. The Ironwood Alliance has submitted field data to her that indicates Seri Indians use of ironwood is sustainable as long as chainsaws are not used in wood harvesting. In addition, the Alliance assisted INI's preparation of a collective trademark request for Seri artisans wishing to safeguard their traditional ironwood designs. SECOFI granted this request in 1995. Printed tags refer to this *marca colectiva* and verify the authenticity of Seri ironwood carvings. However, as Seri carvers do not use the tags regularly, this protection strategy has not yet been effective.

While the Mexican government has initiated components of its comprehensive plan in Sonora, and to a lesser extent in Baja California Sur, Jorge Morachis and Francisco Maytorena of PROFEPA/Sonora, continue to document illegal cutting and export of ironwood. They have requested assistance from both the U. S. Fish and Wildlife Service (USFWS) and the Environmental Protection Agency (EPA) in solving this dilemma.

Legal Protection in the United States

In contrast to México, ironwood has limited protection as a species in the two U.S. states in which it occurs, Arizona and California. Both states require a permit to cut, possess, or transport ironwood. However, neither state has a limit on ironwood permits or the amount of ironwood that can be collected on each permit, nor do they receive sufficient funds to support the execution or enforcement of existing laws. Not a single state or federal agency in the United States has developed a management plan for ironwood resources, despite documented poaching on both state and federal lands.

In Arizona, the Department of Agriculture protects ironwood under the 1990 Arizona Native Plant Law (Arizona Statute Title 3, chapters 903 to 915) in the "harvest restricted" category. According to the statutes, ironwood received this designation as one of the plants "subject to excessive harvesting or over-cutting because of their intrinsic value." Other plants designated as "harvest restricted" include four species of beargrass (*Nolina* spp.), two species of yucca (*Yucca baccata* and *Y. schidigera*), and three species of mesquite (*Prosopis* spp.) (Department of Agriculture, unpublished research). This designation requires anyone taking, transporting, or possessing plant material from these plants to obtain a permit from the department of Agriculture. This does not apply to any amount of the plant less than 100 pounds on land owned or leased by an individual. The permit does not specify an amount that can be removed.

According to James McGinnis (Department of Agriculture, Phoenix Arizona, pers. comm. December 14, 1999), there have been few reported illegal cuttings of ironwood in the Arizona. In 1997, in the Gila Bend area, the Department of Agriculture confiscated six cords of ironwood (taken from approximately 36 trees) that were being removed without a permit. This theft, and one in Organ Pipe Cactus National Monument of 1.5 tons in 1991, is among the few known illegal removals of ironwood in the past few years (C. Connor, Organ Pipe Cactus National Monument, pers. comm.). Mexican nationals continue to cut and remove ironwood from areas north of the Mexican border (Suzan *et al.* 1999). Most of the permits for ironwood go to commercial salvagers in Maricopa and Pima Counties. Of an unknown total number of ironwoods removed by landscapers in 1998, 131 trees were salvaged, compared with 982 mesquite trees and 1201 palo verdes (J. McGinnis, pers. comm. December 14, 1999). Salvage companies estimate the rate of survival to be 90% for salvaged trees. Salvage techniques cost a lot, and once a tree is selected for salvage and "boxed", much work and water are dedicated to its survival. Some trees cost $1000-2000 to box and remove, and at present there is a market for them only in Maricopa County (G. Montgomery, Arizona-Sonora Desert Museum, pers. comm.).

Within certain protected areas, rules have been implemented to protect ironwood from cutting and burning. For instance, Cabeza Prieta National Wildlife refuge implemented a "no burn" rule which has been effective in stopping ironwood destruction for campfire use by visitors and staff.

In California, ironwood occurs in parts of San Diego, Imperial, Riverside, and San Bernadino Counties. Under the California Desert Native Plants Act (sections 80001-80152), the California Food and Agriculture Code protects native desert plants from unlawful harvesting on private and public lands and gives authority to each county to administer permits for harvesting of native desert plants, including both live and dead ironwood. This law specifically states that the agricultural commissioner of each county may establish limits on the amount of ironwood collected, and on the number of permits issued. The commissioner may also adopt such rules and regulations as may be necessary for the protection of the ironwood resource. To our knowledge no such rules or regulations have been adopted.

Part Two: Ironwood Habitat Study

The rest of this report describes our investigation of the effects of ironwood on perennial plant diversity at various sites throughout the Sonoran Desert during the summer and fall of 1999. The purposes of this portion of our study are to compare the influence of the ironwood on perennial plant diversity in different regions of the Sonoran Desert; to assess and contrast the impacts various management strategies and land uses have on ironwood habitats, and to determine which ironwood habitats sampled should be considered priorities for conservation in various regions of the Sonoran Desert.

At each site studied in the U.S./México border states, we compared the perennial plant species richness, diversity and ecological importance of ironwood trees in both ironwood-centered and random plots. Plant diversity is indicated by the abundance or number of each perennial plant species and the evenness, or pattern of distribution of the plant within the study plot. The importance of the perennial plants within the study plot is calculated by multiplying the widest measured diameter of the plant canopy by the abundance of each species. These indices guide us in evaluating the overall impact that the ironwood has on the diversity of plants within its canopy area and allow us to make comparisons with similar areas that do not have an ironwood tree at the center. We categorized our study sites by landform, land-use, and region to make comparisons of our results throughout the Sonoran Desert.

We hypothesized that:

1. More perennial plants should occur in ironwood-centered plots than the random plot they are paired with at sites throughout the Sonoran Desert as indicated by higher species richness, diversity and evenness measures, and higher ecological importance values for ironwood itself.
2. The presence of ironwoods should have high ecological importance values relative to other species at the same sites with regard to their influence on perennial plant cover and abundance in different Sonoran Desert regions than in other regions.
3. Elevation, latitude and longitude should influence plant species richness, diversity and evenness in ironwood habitats.
4. Certain lifeforms of understory species should be influenced by the presence of ironwood more than others, and their degree of association with ironwoods should vary from subregion to subregion.
5. Protected areas within ironwood habitat have greater plant diversity than unprotected areas.

Methods

Site Selection

We chose random sample plots and ironwood-centered plots at 16 known sites within ironwood habitat in three states. We surveyed nine sites in the US and seven sites in México. Three of these sites were on Department of Interior (DOI) lands, in Organ Pipe Cactus National Monument, Saguaro National Park and Cabeza Prieta National Wildlife Refuge. Other sites occurred on lands protected by Mexico'e environmental agency, SEMARNAP, such as the Sierra El Pinacate and Tiboron Island.We selected additional sites to provide us with a range of lands under different levels of protection, land uses, and ironwood extraction. Some sites were located in areas with little or no formal; protection status within the range of ironwood. These lands ranged from state lands to private ranches to land managed by non-profit organizations. We gave special attention to lands currently proposed as parklands in Pima County (Figure 18).

Survey Methods

Once in the field at each site, we sampled vegetation in eight plots: four with an ironwood in the center and four randomly selected plots. Each plot was 512 m^2 plot (12.6 m. diameter) in size. We evaluated richness of perennial plant species, abundance of each species and cover of each species for each plot. In other words, we quantified the number of individual plants per species and the ground area which each species' living growth covered, using a rapid assessment technique called the log plot method developed by McAuliffe (1990). This rapid survey method has been found to be more time-efficient and just as precise as other methods at measuring density and cover of perennial plants in sparsely vegetated arid environments (McAuliffe 1990). Because other ironwood researchers have successfully used this technique in Sonoran desertscrub, we can more easily make comparisons between their data and ours. In addition, we were able to quickly teach this method to our field collaborators, allowing the standardization of how researchers use the log plot method in the field, thereby minimizing biases.

Table 10: Ironwood Plot Locations and Ownership

Ownership	**Site Location**	**County or Municipio**	**Vegetation type**
Department of Interior	Saguaro National Park	Pima	Arizona Uplands
Department of Interior	Organ Pipe Cactus National Monument	Pima	Lower Colorado
Department of Interior	Cabeza Prieta National Wildlife Refuge	Pima	Lower Colorado
State	Tortolita	Pima	Arizona Uplands
State	Cocoraque	Pima	Arizona Uplands
State	Ironwood Picnic Area	Pima	Arizona Uplands
Audubon	Mason	Pima	Arizona Uplands
State	Ragged Top	Pima	Arizona Uplands
State	Casa Grande/Stanfield Road	Pinal	Arizona Uplands
SEMARNAP	El Pinacate	Puerto Peñasco	Lower Colorado
Private	Rancho Carrizo	Benjamin Hill	Plains of Sonora
Tribal	Tecomate	Hermosillo	Central Gulf Coast, Coastal Thornscrub
Private	Calle 12 (Hwy 2)	Hermosillo	Central Gulf Coast, Coastal Thornscrub
Tribal	Santa Rosa	Hermosillo	Central Gulf Coast, Coastal Thornscrub
Ejido/ Communal	Rancho Palo Fierro	Guaymas	Central Gulf Coast, Coastal Thornscrub
Private	Red Mountain	Guerrero Negro	Central Gulf Coast

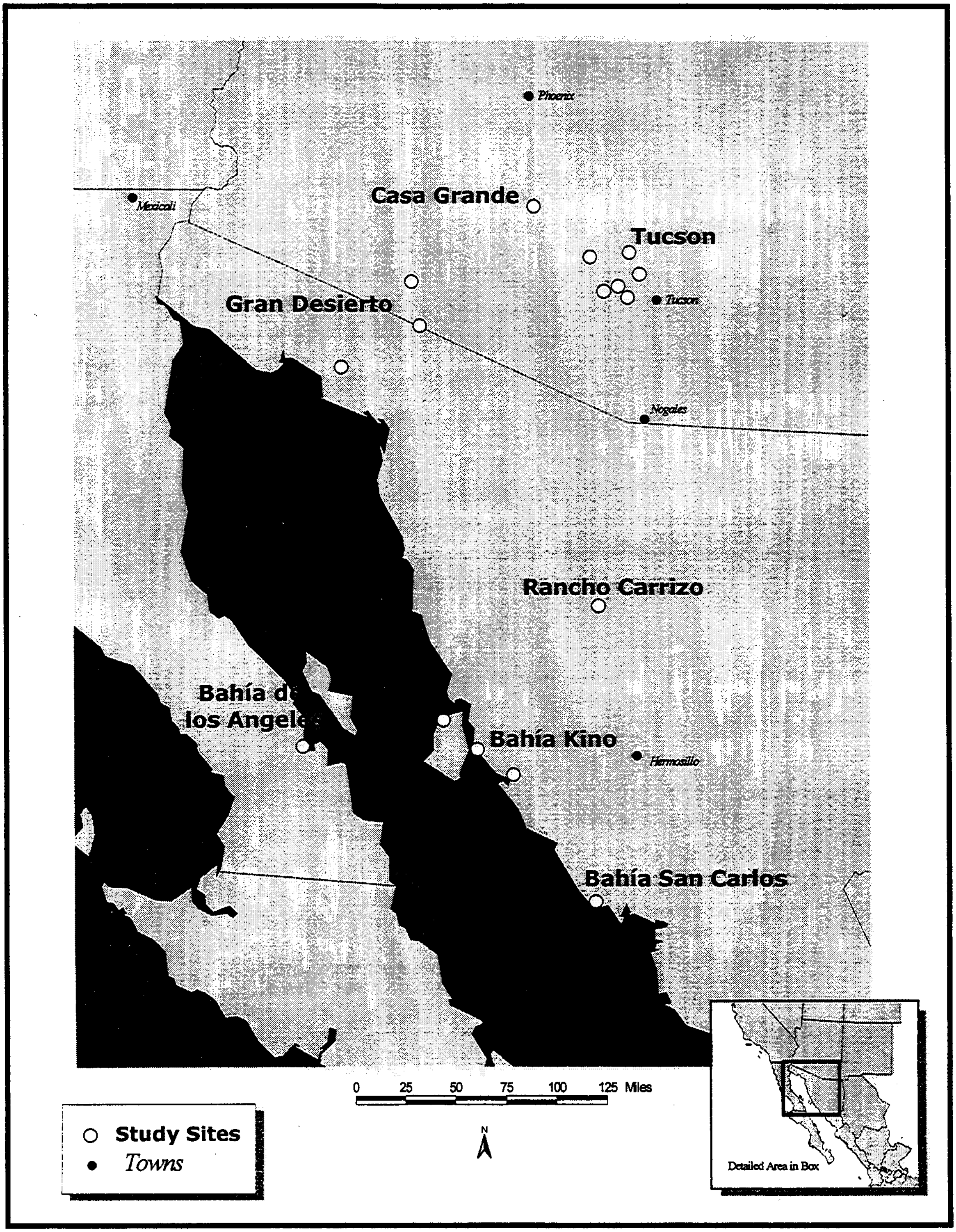


Figure 18: Study sites in the Sonoran Desert selected for this present study.

To assist data collectors in accurately reporting information in a standardized manner, we developed a data collection manual and an associated data sheet (Appendix IV). For each plot, we counted the abundance of each perennial species of vascular plant in one of two ways. For those plant species with a low abundance, or species not equally represented on the entire plot, we assessed abundance by counting individual plants. For plants with a large number of individuals widely represented over the entire plot, we counted individuals in one quarter of the plot, then multiplied that number by four to estimate the total abundance of that species for the entire plot. To determine cover amounts for each plant we measured the widest diameter of each of five individuals of that species, then averaged those measurements. We recorded the annual plants present, and whether they were native or exotic.

For each ironwood-centered plot, we permanently tagged the base and measured the canopy size, number of trunks and size of trunks. We also recorded each perennial and annual plant species found directly under the central nurse plant's canopy.

To compare and analyze the patterns of plant diversity between sites and regions we recorded landforms and land uses at each site. To evaluate the effect of protection status and human impact we documented any evidence of chainsaw or ax cutting, grazing or any other disturbance on the plot. We noted the presence or absence of bird nests or other signs of wildlife on each plot.

Data Analysis

We used cover and abundance data from each plot to calculate several measures of diversity as well as other parameters of interest to conservation biologists. We first tallied species richness (the number of perennial species per plot), then calculated several other measures: the anti-log of the Shannon-Weiner diversity index (which uses the numbers of individual of each species and total number of species a measure of heterogeneity which is weighted toward the dominant species); the Simpson diversity index (which uses the same factors, but weights this measure of plant diversity toward the relative numbers of rare species); an integrative index for evenness of plant distribution (which combines the other two diversity indices), and an index of ecological importance (which rates the relative importance of ironwood's contribution to each plot's total cover and abundance). For further explanation of these measures, see Ludwig and Reynolds (1988).

Once these values were calculated for each plot, we used regression models in the SPSS statistical software program to compare the slopes of random versus ironwood-centered plots in terms of the relationship between canopy cover contribution and the plant diversity values. Next we checked the effects that latitude, longitude and altitude had on plant species richness, cover, diversity and ecological importance values for ironwood using multiple correlation statistical analyses. We then tested differences in the diversity values for ironwood-centered and random plots at each site for significance using the Student 't' test (Hair *et al.* 1992). Finally, we compared the importance values of different lifeforms associated with ironwood to determine if specific groups of understory plants can be used as indicators of geographic differences in plant guilds. To do this, we used a cluster analysis statistical method known as "Decorana," or detrended correspondence analysis (Ludwig and Reynolds 1988).

In our next set of analyses, we categorized all perennial plants found in the plots by their lifeform: epiphyte; tree; large shrub; large cactus; medium shrub; medium cactus; small perennial herb; small cactus; and vine. We compared the relative ecological importance of each lifeform by subregion. We then attempted to detect whether there were any significant interactive effects between lifeform and the plot type (ironwood-centered versus random) in each subregion, using an analysis of variance (ANOVA) test to do so.

Mapping and Geographic Information Systems (GIS)

Using a Garmin 12 handheld GPS receiver, we recorded plot locations in UTM coordinates. We recorded elevations using the Garmin, then corrected these records using topographical maps. Using ARCVIEW software, we created study and site location maps. All site locations and data will be filed in an ARCINFO-EXCEL relational database maintained by Carlos Valdes and staff at CICARENA at the ITESM campus in Bacochibampo near Guaymas, Sonora. We will include these data in a larger geographic database for the Migratory Pollinators Project.

Results

Comparison of ironwood-centered and random plots

Our first set of analyses compared plots centered on ironwood trunks with random plots situated at the same sites, in the same habitats. We clustered all plots in the same subregion of the Sonoran Desert (eg. Arizona Upland) to determine whether there were geographic differences in the effects of ironwood on species richness, cover, abundance and diversity of perennial plants. We will present results by subregion, then summarize trends for the region as a whole.

For the Arizona Uplands subregion of the Sonoran Desert, which includes much of Pima County and adjacent Sonora, ironwood exerted a statistically significant influence on community cover values. The measure we used to assess ecological importance showed higher values in ironwood-centered plots than in random plots (Figure 19). There were no other statistically significant differences between ironwood-centered and random plots in the Arizona Uplands. (Table 11). However, the ironwood-centered plots tended to have higher levels of species richness and Shannon-Weiner type diversity, weighted toward heterogeneity of dominant species.

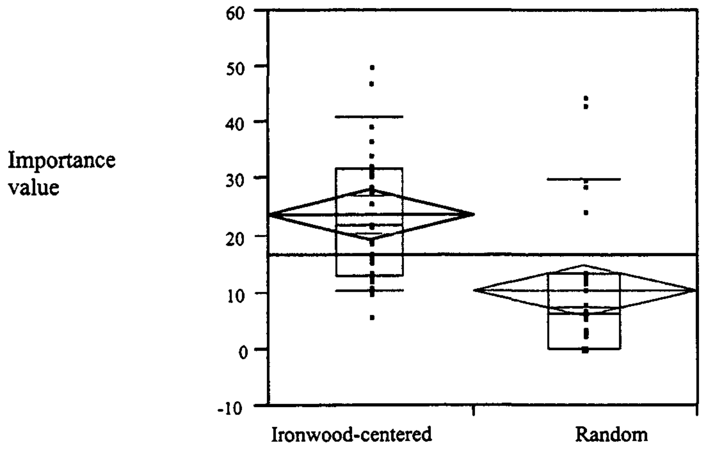


Figure 19: Ecological Importance values for nurse and non-nurse-centered plots in the Arizona Uplands subregion.

Table 11: ANOVAS between nurse-centered and random plots for the Arizona Uplands.

INDEX	F (1,54 d.f.)	P
Shannon-Weiner Diversity, weighted toward dominants	0.85	.36
Simpson Diversity, rare sp. weighted	0.59	.45
Evenness	0.001	.975
Ecological Importance value	16.49	.0002

We found a similar pattern in the Lower Colorado River Valley subregion (Figure 20). Ironwood-centered plots had significantly higher ecological importance values, but while there were trends toward higher values in ironwood-centered plots for the Shannon-Weiner diversity index (weighted toward a heterogeneity of dominants), for the Simpson diversity index (weighted toward a heterogeneity of rare species), and for evenness, the differences were not statistically significant (Table 12).

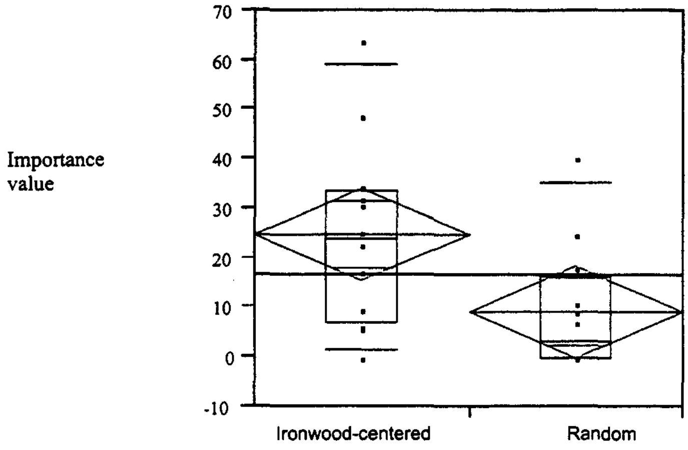


Figure 20: Ecological Importance values for nurse versus non-nurse plots in the Lower Colorado River Valley subregion

Table 12: ANOVAs between ironwood-centered and random plots for the Lower Colorado River Valley subregion

INDEX	F (1,22 d.f.)	P
Shannon-Weiner Diversity, weighted toward dominants	0.89	.35
Simpson Diversity, rare sp. weighted	0.98	.33
Evenness	1.12	.30
Ecological Importance value	5.66	.03

We were unable to detect any statistically significant differences for any factors in the Plains of Sonora or Central Gulf Coast of Baja California sample plots. However, the Central Gulf Coast of Sonora plots showed very strong differences in ecological importance values (Figure 21). In other words, the presence of ironwood in the Central Gulf Coast of Sonora plots dramatically increases total vegetative cover per plot, and therefore its ecological importance is statistically significant. There is a weak trend toward higher species richness and Shannon-Weiner diversity weighted toward dominants in ironwood-centered plots, but no other positive effect of ironwood's presence could be detected (Table 13).

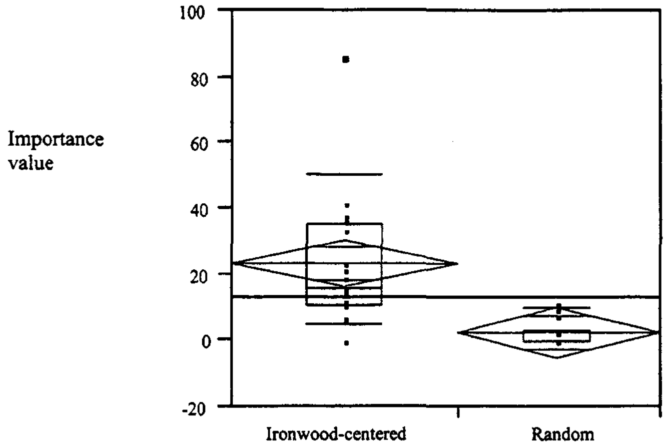


Figure 21: Ecological Importance values for nurse versus non-nurse plots in the Central Gulf Coast of Sonora

Table 13: ANOVAs between ironwood-centered and random plots for the Central Gulf Coast of Sonora

INDEX	F (1,30 d.f.)	P
Shannon-Weiner Diversity, weighted toward dominants	0.19	.26
Simpson Diversity, rare sp. weighted	0.018	.89
Evenness	1.46	.24
Ecological Importance value	15.17	.0005

In the region overall and among subregions, there are statistically significant differences in vegetative cover between ironwood-centered versus random plots, independent of the species abundance per plot. The Arizona Upland and Central Gulf Coast subregions have significantly more cover in ironwood-centered plots than in random plots, and significantly more cover in all their plots than do plots in the Lower Colorado River Valley and Plains of Sonora subregions.

When sites from all the subregions are collapsed to detect possible interactions among various factors influencing species richness, only the Arizona Uplands and the Central Gulf Coast subregions demonstrated statistically significant patterns of dominance rated toward dominant species. While we found significant differences among subregions, no region-wide differences in patterns of species richness between ironwood-centered and random plots, nor any interactive effects of subregion combined with plot type (ironwood-centered versus random) were detected. (Figure 22).

Response: NO

Summary of Fit

RSquare	0.105168
RSquare Adj	0.036919
Root Mean Square Error	5.976961
Mean of Response	13.84375
Observations (or Sum Wgts)	128

Parameter Estimates

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
REGION	4	4	410.13095	2.8701	0.0260
STATUS	1	1	8.14583	0.2280	0.6339
STATUS*REGION	4	4	41.45553	0.2901	0.8839

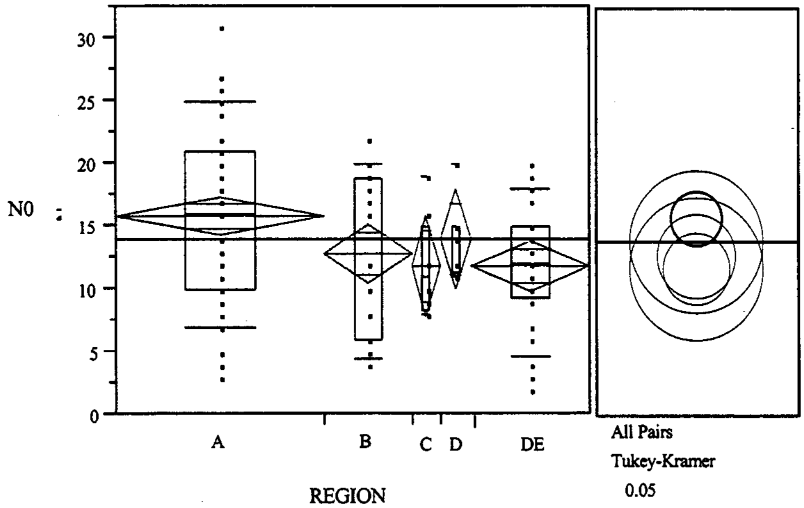


Figure 22: Shannon-Weiner analysis of diversity weighted toward dominant species for all the subregions clumped together.

The influences of the rarely-encountered plants on perennial plant diversity (Simpson index) values per plot were significant only in the Central Gulf Coast of Sonora. (Figure 23). We found fewer species per plot in the Central Gulf Coast of Sonora, but greater differences among plots in which rare species were present.

```
Response:        N1
 Summary of Fit
 RSquare                                     0.097675
 RSquare Adj                                 0.028853
 Root Mean Square Error                      3.395373
 Mean of Response                            5.809275
 Observations (or Sum Wgts)                    128

 Parameter Estimates

 Effect Test
 Source              Nparm  DF    Sum of Squares    F Ratio    Prob>F
 REGION                4     4      127.28728        2.7603     0.0309
 STATUS                1     1        6.39219        0.5545     0.4580
 STATUS*REGION         4     4        7.46819        0.1619     0.9572
```

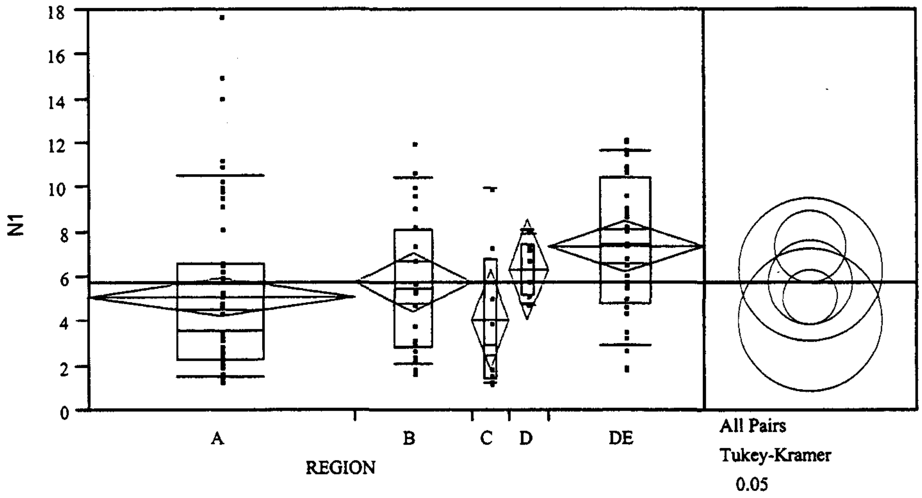


Figure 23: Simpson diversity index values, weighted toward rarely-encountered species, for all regions clumped together.

A similar pattern emerged from analyses of evenness of perennial plant diversity, which value how evenly various species contribute to the number of plant individuals per plot. Evenness levels were highest in the Central Gulf Coast of Sonora and lowest in the Arizona Uplands subregion. We found no other statistically significant differences due to subregion and plot type, nor any interactive effects (Figure 24).

Response: Even-ness

Summary of Fit

RSquare	0.388783
RSquare Adj	0.342165
Root Mean Square Error	0.142194
Mean of Response	0.576661
Observations (or Sum Wgts)	128

Parameter Estimates

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
REGION	4	4	1.4579456	18.0268	<.0001
STATUS	1	1	0.0077629	0.3839	0.5367
STATUS*REGION	4	4	0.0675729	0.8355	0.5052

E5

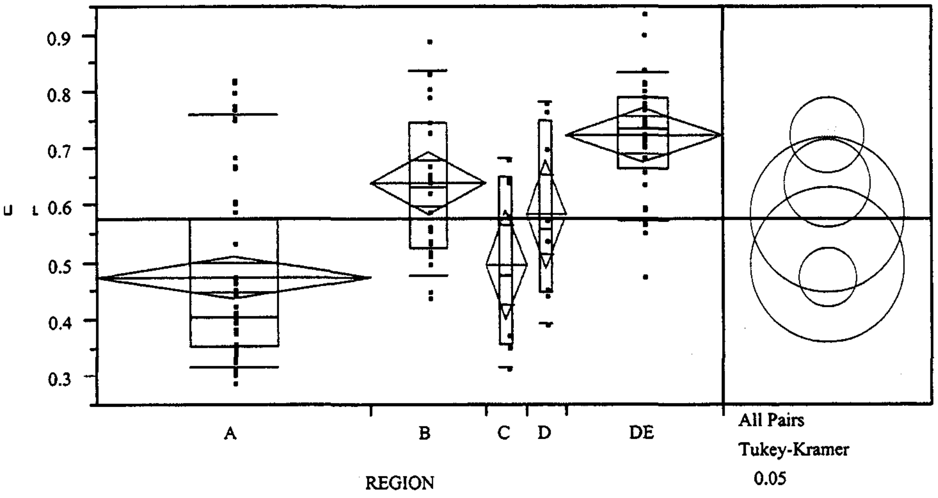


Figure 24: Analysis of evenness for all regions clumped together.

With regard to the measure of ecological importance based on cover as well as abundance values, ironwood as a species is unsurpassed in this importance in influencing vegetative cover and abundance in plots wherever we found it in the Sonoran Desert. The differences in ecological importance values between ironwood-centered and random plots in cover and abundance are highly significant in every subregion where we studied it. In other words, ironwood is as important to community structure in one subregion as it is in another. If ironwood was removed from any of these habitats, we would expect cover and abundance of perennial plants to decline.

When we attempted to correlate species richness, diversity, evenness, and ecological importance values with elevational, latitudinal, and longitudinal patterns, we found statistically significant trends for species richness and evenness. Species richness correlated strongly with elevation, with a greater number of species present in upland sites than in coastal sites. Evenness decreased with increasing elevation and latitude. In other words, as one moves upward and away from our coastal sites, the eveness in contribution to abundance and cover made by various species decreases.

Finally, we reviewed all plots with the highest values for species richness, diversity and importance. The Ragged Top site on the Pima-Pinal County boundary contributed the highest levels of species richness with six of the ten plots having the highest levels within the entire region. Two plots in the Ironwood Picnic Area in Pima County's Tucson Mountain Park also were found to have diversity values.

For the Shannon-Weiner diversity index weighted toward dominant plant species, the Ironwood Picnic Area in Pima County contributed the three highest values, followed by three plots from Punta Santa Rosa in coastal Sonora. For the Simpson diversity index weighted toward rare species, three plots at the Ironwood Picnic Area in Pima County again contributed the highest values, but Punta Santa Rosa and Rancho Palo Fierro contributed four plots and two plots, respectively, to the top ten. In terms of evenness, Tecomate Valley on Tiburón Island contributed the highest evenness value, as well as the third highest evenness value of any plot. Rancho Palo Fierro, the Ironwood Picnic Area and the Pinacate also had two or more sites in the top ten.

With regard to ecological importance values, Rancho Palo Fierro had the highest single value. Other sites with two or more plots in the top ten included Rancho Carrizo on the Plains of Sonora, the Pinacate site in northwest Sonora, and Cocoraque in Pima County.

Analysis of Lifeforms Associated with Ironwoods

We found significant differences in importance values among lifeforms, but no significant sole effects of plot type or of sub-region (Table 14). Significant interactive effects occurred between lifeform and plot type. In other words, the presence or absence of ironwood created interactive effects with various lifeforms. In addition, there were interactive effects between subregion and lifeform for ecological importance values. This suggests that different lifeforms are favored under ironwood in different subregions of the Sonoran Desert. To better understand how ironwood's presence influences the lifeform mixes in its understory, we undertook additional non-parametric (median) tests and graphic analyses.

Table 14: Analysis of importance values of lifeforms for various subregions, with or without ironwood nurses.

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
region	4	4	18.71	0.0095	0.9998
nurse	1	1	1.57	0.0032	0.9550
grw	8	8	312723.73	79.1572	<.0001
nurse*subregion	4	4	6.24	0.0032	1.0000
nurse*growthform	8	8	9912.88	2.5092	0.0106
subregion*growthform	32	32	127355.18	8.0591	<.0001
nurse*subregion*growthform	32	32	11879.83	0.7518	0.8400

In the first set of median tests, we found significant differences among the lifeforms in terms of their importance values. Medium shrubs had the highest importance values, followed by large shrubs and small perennials. When the interaction between lifeform and plot type was analyzed by median tests for all subregions, we found significant differences in importance values between ironwood-centered and random plots for vines which are structurally supported by ironwood trunks, and to a lesser degree for small perennials and for trees. In the Arizona Uplands, Lower Colorado River Valley, and Central Gulf Coast subregions, we found statistically significant differences in the importance values of vines in ironwood-centered versus random plots. In the Plains of Sonora, we found statistically significant differences in the importance values of small herbaceous perennials, large shrubs, and medium shrubs in ironwood-centered versus random plots.

Finally, we generated a matrix of lifeform presences in various plots to make an analysis of detrended correspondences. This analysis indicates which understory species best serve as indicators of distinctive species composition in certain plots. The species that serve as indicators of southerly, coastal plots with distinctive composition include two trees (*Forestiera mexicana, Bursera laxifolia)*, several vines (*Cocculus diversifolius, Gouania rosei,* and *Struthanthus palmeri),* two shrubs (*Justicia sonorae* and *Jacquinia macrocarpa)*, and a small perennial (*Elytraria imbicata*). In the northwest, the scandent cactus, *Peniocereus striatus*, is a useful indicator of subregion uniqueness. Elsewhere in the north, two herbaceous perennials (*Proboscidea altheafolia* and *Ambrosia confertifolia*), and one vine (*Cucurbita digitata*) may serve as indicators of distinctive composition.

In general, these results suggest dramatic differences in the understory composition of vines and small herbaceous perennials associated with ironwoods growing in different subregions. While ironwood is equally important to lush cover and abundant populations of perennial plants throughout many habitats in the Sonoran Desert region as a whole, it fosters different loosely-structured guilds of understory plants in different subregions.

Discussion

The presence of canopies of mature ironwoods in any habitat increases the total vegetative cover and perennial plant abundance relative to other areas of equivalent size in the same habitat. In all of the Sonoran Desert subregions sampled, ironwood is among the most ecologically important species present because its presence increases the total vegetative cover of other associated plants. This implies that if ironwoods were eliminated from these habitats, there would be a decrease in the lushness of the vegetation and the density of associated plants.

The loss of ironwood alone is not likely to decrease the total species richness found at particular sites if other tree legumes functioning as nurse plants persist at these sites. In many cases, however, all other tree legumes on a site face the same threats as ironwoods do. When desert hardwoods are targeted for charcoal production, all sizeable woody legumes may be removed from a site at the same time. When this happens, it is likely that species richness and diversity decline with the loss of all sizeable legume trees functioning as nurse plants. Similarly, buffelgrass invasions and subsequent wildfires may decrease survivorship of all young legume trees, not only ironwood (Búrquez and Quintana 1994, Warren 1994, Esque in press).

The degree of influence of ironwood on various indicators of biodiversity varies from subregion to subregion. The Arizona Uplands and Central Gulf Coast exhibit the greatest difference in patterns of diversity. The sites in the Central Gulf Coast have a smaller total number of species present, but dominance varies more from site to site. The Arizona Uplands sites have more species per site, but a few dominant species tend to be shared at all sites within the subregion. Within the region as a whole, the following sites contribute the highest values of significance to biodiversity conservation: Ragged Top, Ironwood Picnic Area, and Cocoraque in southern Arizona; and Punta Santa Rosa, the Pinacate, Rancho Carrizo, and Tecomate on Tiburón Island in México.

While ironwood functions as an important habitat-modifying keystone species throughout the Sonoran Desert region, it harbors different sets of understory plants in each subregion. In particular, the perennial plant guild found beneath ironwood canopies in the Arizona Uplands may have little overlap with the guild found in the Central Gulf Coast adjacent to the Sea of Cortéz. Understory vines which use ironwood canopies as trellises are among the components of vegetation with greatest turnover from site to site or from subregion to subregion. In addition, ironwood influences the relative ecological importance of vines more than it does other lifeforms.

Overall, the perennial plant diversity in ironwood-centered plots tends to be greater than that in stratified random plots, but the difference is not significant for the region as a whole. Instead, we see more significant differences in the measure of ecological importance based on vegetative cover measurements. Particularly in the Central Gulf Coast of Sonora, we found that the presence of ironwood significantly increased vegetative cover. The specific effect of the buffered microenvironments created by ironwood canopies is to increase the standing crop of the understory plants, probably by decreasing environmental stresses on those plants. In the more northerly, inland populations, ironwood shows extremely high importance values.

In general, our results are consistent with those earlier field studies by Búrquez and Quintana (1994), Suzán *et al.* (1994) and Tewksbury and Petrovich (1994). They established the preeminent importance of ironwood as a habitat-modifying keystone in the Central Gulf Coast, Plains of Sonora, and Lower Colorado River Valley subregions of the Sonoran Desert. We can now extend this ecologically-influential status to ironwoods occurring in Arizona Uplands as far north as Pima, Pinal, and Maricopa Counties in Arizona, and to ironwoods occurring in Desertscrub–Coastal Thornscrub transition in the Municipio of Guaymas, Sonora. Carrillo-Garcia *et al.* (1999) independently confirmed that ironwood is second only to mesquite in ecological importance in the Desertscrub-Cape Thornscrub transition near La Paz, Baja California Sur.

Mesquites, palo verdes, mimosas and acacias also function as valuable nurse plants for most of the species found under ironwood canopies (Carrillo-Garcia *et al.* 1999; Spigler 1999). However, each of these tree species has distinctive light, moisture and trellis traits that favor the growth of some species or certain lifeforms more than others (Castellanos *et al.* 1999). In particular, ironwood functions as the most important nurse plant for vines in the Plains of Sonora, and probably in other subregions as well.

In flat desertscrub habitats within the flats of the Plains of Sonora subregion, 54% of all climbing vines encountered grew under ironwood trees (Molina and Tinoco 1997). Along washes, ironwoods served as trellis or nurse plants for a smaller percentage of all vines, since the availability of other potential nurse plant species was far higher. Even there, however, the number of individual vines per tree was four times higher under ironwood than under any other tree alongside the channels of washes (Molina and Tinoco 1997).

We recorded the highest levels of species richness among the climbing vine lifeform near the most southerly reaches of ironwood's range. Ironwood also remains important to the few vines that grow elsewhere, as far north as the Arizona Uplands.

Within each subregion of the Sonoran Desert, there are different roles which ironwood plays on the *bajadas*, or rocky slopes, on alluvial flats, and on wash banks.

The abundance and cover of other understory plants associated with ironwoods in xeroriparian (wash) habitats is considerably different from those on desert alluvial plains and rocky slopes (Molina and Tinoco 1997, Tewksbury *et al.* 1994). Other large trees co-occur with ironwoods along washes, but ironwoods may be the only tall branching woody plants on the valley floors or bajada slopes (Vander Wall 1980). Their relative influence on plant and wildlife diversity is proportionally greater in plains and rocky slope habitats above ephemeral and intermittent watercourses. Along watercourses, ironwood is but one of many nurse plants available.

Our observations corroborate earlier observations that not all size-classes of ironwoods function as effective nurses. The canopy size and foliar density of an ironwood are strong factors influencing their relative value as nurses. Medium-sized mature ironwoods harbor a greater diversity of understory plants than either ironwood saplings or the largest, ancient shade-forming ironwoods (Tewksbury and Petrovich 1994, Suzán *et al.* 1996). However, our recent field observations suggest that some mid-sized trees do not necessarily serve as nurses for many plants, especially if grazing is heavy. There is no significant correlation between increasing ironwood canopy size, understory species richness, and the number of vines per nurse tree, perhaps due to the effects of grazing (Molina and Tinoco 1997).

We are still analyzing our data in an attempt to determine how factors such as grazing, exotics and woodcutting affect ironwood habitat diversity and ironwood regenerative capacity (Suzán *et al. 1999*). There are preliminary indications that both woodcutting and buffelgrass competition can decrease understory species richness and diversity (Suzán 1994, Búrquez and Quintana 1994).

We have also documented that ironwood cutting can result in greater damage to understory plants (Nabhan and Suzán 1994, Suzán *et al.* 1999). Nurslings exposed by woodcuting have a greater probability of succumbing to radiation damage and breakage via trampling, or to death due to browsing (Nabhan and Suzán 1994). Solís-Garza and Espericueta (1997) have confirmed that virtually no ironwood regeneration had occurred to date in areas where commercial woodcutting has been permitted in Sonora. If the loss of mature ironwood nurse plants disrupts the regeneration of both ironwood and its understory associates for several decades, it is plausible that maturation of giant cactus forests could be arrested for tens if not hundreds of years. Like other nurse plants, ironwoods must be protected to maintain the regeneration dynamics of rare plant populations which grow under its canopies (Franks 1999). Numerous threatened and endangered plants are associated with ironwood nurses, as Appendix III indicates. Although we did not systematically record the fauna found in or under ironwood canopies at the 148 new plots we measured, it initially appears as though plots with high intensity woodcutting, weed invasions, or fragmentation were often de-faunated. More analysis is required to verify these trends. Appendix III, which lists animals of conservation concern that regularly use ironwood habitats, can be used as a tool for future studies of this kind.

Recommendations

Over the last decade, several meetings of scientists, activists and ironwood users produced recommendations for future research, conservation, and use of ironwood and its habitats (Mellink, Nabhan and Suzán 1994; Nabhan and Carr 1994; Paredes and López 1995; Solís-Garza and Vásquez de Castillo 1998; SEMARNAP 1997). These recommendations spurred actions, some of which have now been accomplished. However these actions raised other issues which we have listed below as a guide to future initiatives.

Resolving the Knowledge Gap

Plant Interactions

- Further elaborate differences between ironwood and mesquite as nurse plants, comparing their canopies at the same sites for influences on soil composition and moisture-holding capacity, spatial use of climbing vines, and nursling mortality after catastrophic freezes.
- Establish more definitively whether there are characteristic plant guilds associated with ironwood canopies in each subregion.
- Determine ironwood survivorship in habitats invaded by buffelgrass, Sahara mustard, or other fire-carrying exotics.

Animal Interactions

- Determine, more definitively, the diversity of animals (mammals, birds, reptiles, insects, spiders, amphibians, etc.) which use ironwood for cover and food.
- Verify the importance of dead (standing) ironwood snags as roosts for hawks and owls.
- Clarify the degree of dependence by pygmy owls in desertscrub habitat on ironwoods.
- Determine the intensity of ironwood use by migrant animal species, especially pollinators.

Longevity of Ironwood

- Establish the longevity of ironwood trees and elaborate size class/age class correlations at long-term study sites, such as Organ Pipe Cactus National Monument, where dendrometers have already been fitted to tree trunks.

Human Impacts on Ironwood

- Determine the threshold effects of ironwood habitat fragmentation on obligately cross-pollinated understory plants, such as night-blooming cereus, acuña cactus, or Tumamoc globeberry.

- Through low level aerial photographs or other methods, document precisely the amount of prime ironwood habitat being lost to development by region, with a priority on rapid growth areas such as Pima County, Arizona. Develop this data into GIS vegetation layers.

- Determine the amount of dead wood available in different areas, and the rates at which it accumulates or is depleted.

- Establish relationships between ironwood trunk diameters, canopy areas, cordwood volumes, as well as resulting charcoal and carving volumes or cash values per tree or per cubic meter of dead wood.

Regulating Uses and Sustainability

- Require environmental assessments to determine the extent of ironwood destruction before issuing development permits.

- Require developers to pay for ironwood salvage and relocation.

- Determine the economic value derived from the same volume of wood (or trees per hectare) when left intact for ecotourism and wildlife, when crafted into carvings, and when reduced to charcoal.

- Determine the ecological, cultural and economic values of associate plants specific to ironwood.

- Stockpile ironwood removed from lands condemned for road building and construction to offer carvers in exchange for their voluntary commitment to refrain from cutting live trees.

- Discourage the granting of mesquite-cutting permits in areas where ironwood co-occurs, and provide PROFEPA with more support to verify whether mesquite permits are used only for mesquite.

- Provide incentives such as higher fees to discourage the use of chainsaws to cut live ironwoods, and fine those who are caught girdling live trees for later harvesting as "dead wood."

- Provide the Seri and others who carve sustainable-harvested wood with "green certification" tags from the Forestry Stewardship Institute, and promote their carvings in ways which contrast their products with those made of illegally or unsustainably harvested wood.

- Tax importers of ironwood products to the U. S. and return these funds to PROFEPA in Sonora and Baja California to better monitor or phase out all ironwood cutting.

Educating the Consumers

- Raise awareness among school children, amateur naturalists and decision-makers about ironwoods, both how ancient they are, and the many wildlife species they harbor under their canopies.

- Remind U.S. consumers their use of charcoal made in Mexican deserts causes wildlife habitat destruction and pollution. The U.S. EPA does not allow the same pollution-generating charcoal production techniques to be practiced in the U.S.

- Raise awareness among potential purchasers of machine-made ironwood carvings that ironwood cutting may be destroying the habitat of the very animals depicted in the figurines.

- Use ironwood habitats to showcase the high levels of biodiversity associated with certain desert habitats.

- Discuss with students the ethics of conservation and economic use of a binational resource shared by different, but interdependent economies.

Ensuring Protection

- Designate and enforce "extraction-free sanctuaries" in both countries in areas with high densities of ironwood.

- Designate and develop comprehensive management plans for Unidades de Manejo y Aprovechamiento (UMA- Sustainable Harvesting Areas) in both countries and establish limits on dead wood extraction through comparative analyses with the extraction-free sanctuaries.

- Fund the reforestation of ironwood and mesquite and ecological restoration of their habitats through taxes or tariffs on ironwood and mesquite products.

- Prioritize the establishment of ironwood habitat protected areas in subregions of the Sonoran Desert which currently lack them (Plains of Sonora, Central Gulf Coast of Baja California).

- Plan and implement different protection strategies for wash, rocky slope and valley/plains ironwood habitats in each of the Sonoran Desert subregions.

- Encourage ranchers to protect ironwood on private lands in areas currently free of buffelgrass, and give them tax breaks for doing so.

- Devise a corridor of stepping stone reserves within ironwood habitats stretching from Guaymas to the Gila River, for the benefit of migratory species.

- Give priority protection to areas of prime ironwood habitat such as Ragged Top and Cocoraque Rock in southern Arizona, and Punta Santa Rosa north of Kino, Tecomate Valley on Tiburón Island and Rancho Palo Fierro near San Carlos in Sonora.

- Provide more comprehensive management guidelines for prime ironwood habitat in existing protected areas such as Saguaro National Park, Organ Pipe Cactus National Monument, the Sierra Pinacate and Gran Desierto del Altar Biosphere Reserve, and Rancho El Carrizo.

- Support regular meetings of a binational advisory committee on ironwood protection that could evaluate the progress in developing UMAs and protected areas, and determine other research and education needs.

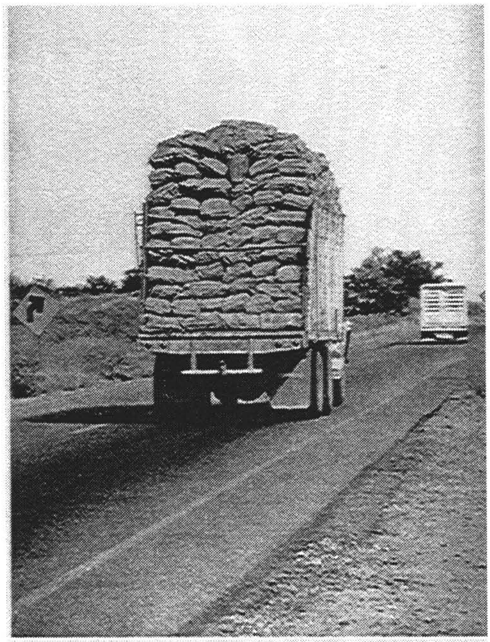


Figure 25: Flatbed truck loaded with mesquite and ironwood charcoal on its way to the United States from Central Sonora (David Burckhalter 1994 photo, courtesy of Gary Nabhan and Conservation International).

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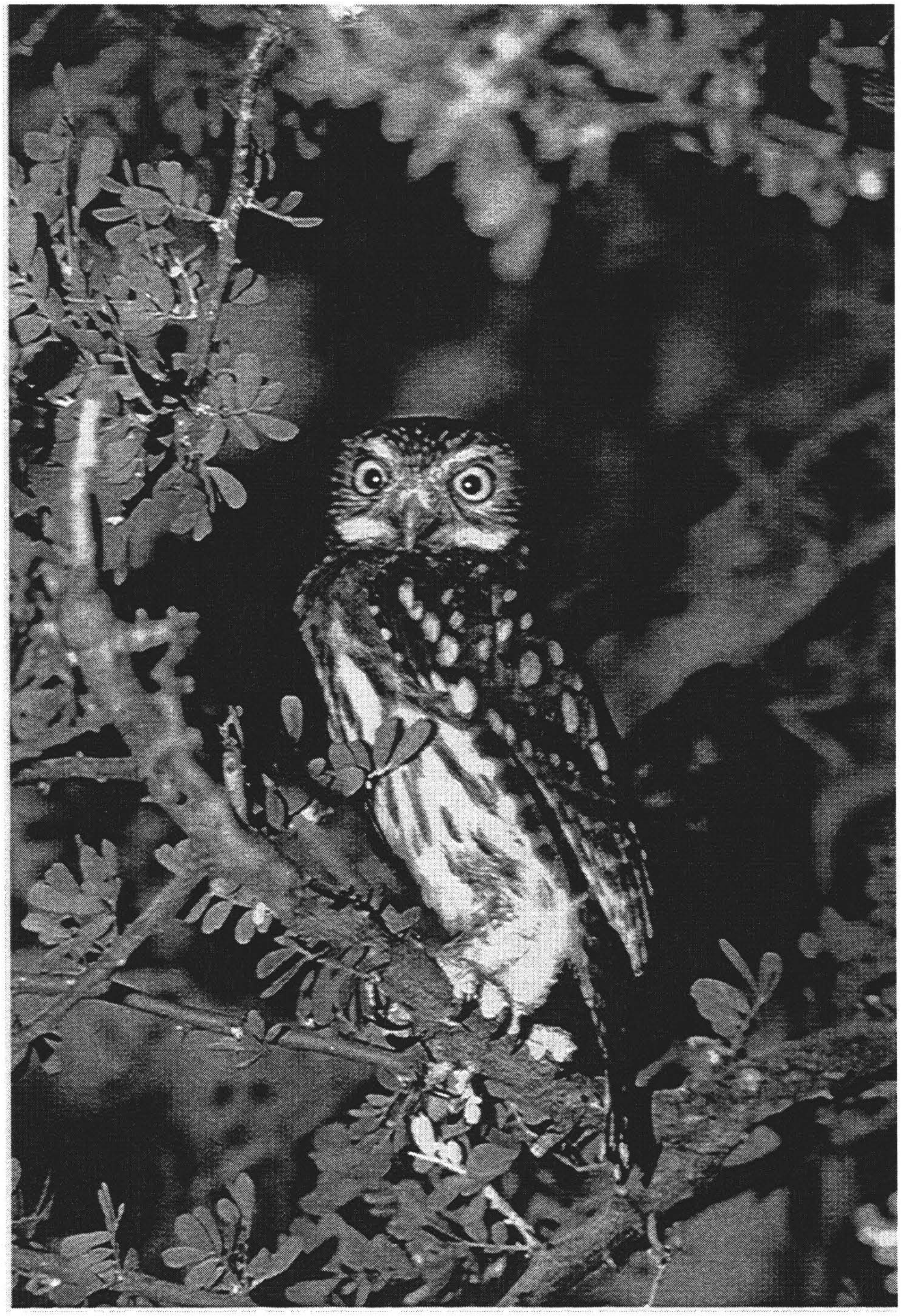
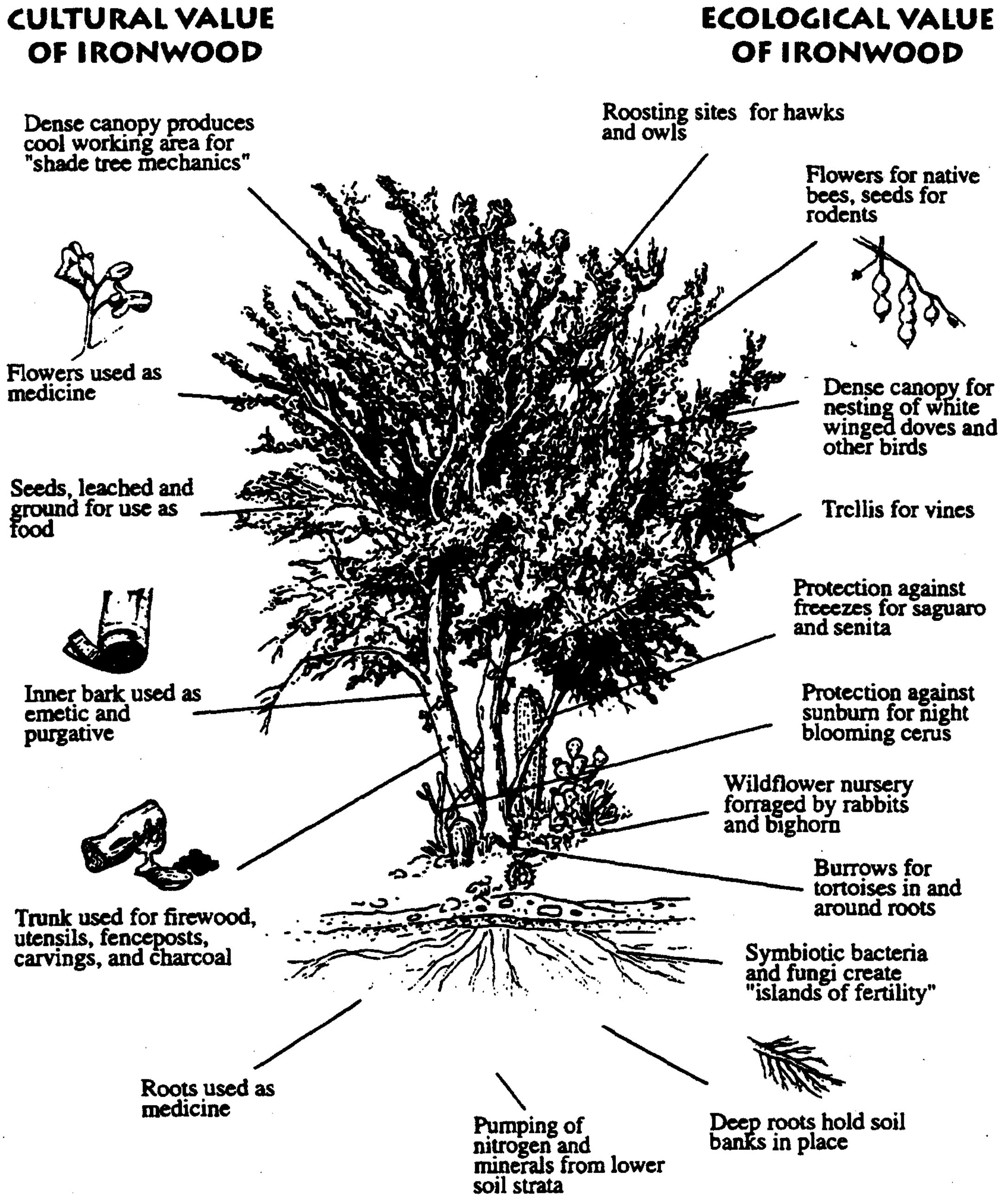


Figure 26: Pygmy owl fledgling perched in an ironwood tree on the northwest side of Tucson (photo by Michael Terrio, 1998).

IRONWOOD

Olneya tesota



Appendix I: Plants Found Under Ironwwood

Family	**Species**
Acanthaceae	Anisacanthus thurberi
	Berginia virgata
	Carlowrightia arizonica
	Justicia californica
	Justicia longii
	Ruellia californica
Achatocarpaceae	Phaulothamnus spinescens
Agavaceae	Agave datylio
Amaranthaceae	Amaranthus sp.
	Amaranthus fimbriatus
	Amaranthus palmeri
	Tidestromia lanuginosa
Apocynaceae	Matelea cordifolia
Aristolochiaceae	Aristolochia watsonii
Asclepiadaceae	Sarcostemma cynanchoides
Asteraceae	Acourtia wrightii
	Ambrosia ambrosiodes
	Ambrosia confertfolia
	Ambrosia cordifolia
	Ambrosia deltoidea
	Ambrosia dumosa
	Ambrosia ilicifolia
	Aplopappus spinulosus
	Baccharis salicifolia
	Baccharis sarothroides
	Bebbia juncea
	Brickellia coulteri
	Chaenactis stevoides
	Conzya coulteri
	Coreocarpus parthenioides
	Encelia farinosa
	Encelia farinosa var. phenicodonta
	Encelia fructescens
	Hymenoclea monogyra
	Hymenoclea salsola
	Hymenothrix wislizenii
	Isocoma acradenia
	Isocoma tenuisecta
	Machaeranthera coulteri
	Palafoxia linearis
	Parthenium incanum
	Pectis papposa
	Perityle emoryi
	Porophyllumm gracile
	Psilostrophe cooperi
	Stephanomeria pauciflora
	Thymophylla concinna
	Trixis californica var. californica

Appendix I: Plants Found Under Ironwwood

Family	**Species**
	Zinnia acerosa
Bignoniaceae	Chilopsis linearis
Boraginaceae	Cryptantha augustifolia
	Cordia parvifolia
Brassicaceae	Brassica sp.
	Colanthus sp.
	Descurainia pinnata
	Lepidium lasiocarpum
	Lepidium perfoliatum
	Lyrocarpa coulteri
	Thelypodium sp.
Burseraceae	Bursera hindsiana
	Bursera laxiflora
	Bursera microphylla
Cactaceae	Carnegiea gigantea
	Echinocereus fendleri robustus
	Echinocereus spp.
	Echinomastus erectocentrus
	Ferocactus cylindraceus var cylindraceus
	Ferocactus diguetii
	Ferocactus emoryi
	Ferocactus wislizenii
	Lophocereus schottii
	Mammillaria grahamii
	Mammillaria mainae
	Mammillaria tetrancistra
	Mammillaria thornberi
	Opuntia acanthocarpa
	Opuntia arbuscula
	Opuntia bigelovii
	Opuntia cholla
	Opuntia ciribe
	Opuntia phaecantha/engelmanii
	Opuntia fulgida
	Opuntia leptocaulis
	Opuntia violacea
	Pachycereus pringlei
	Peniocereus greggii
	Peniocereus striatus
	Stenocereus gummosus
	Stenocereus thurberi
Capparidaceae	Atamisquea emaginata
	Forchammeria watsonii
Celastraceae	Castela peninsularis
	Maytenus pyllanthoides
Chenopodiaceae	Atriplex barclayana
	Atriplex canescens
	Atriplex linearis

Appendix I: Plants Found Under Ironwwood

Family	**Species**
	Atriplex polycarpa
	Chenopodium murale
	Salsola australis
	Suaeda moquinii
Commelinaceae	Commelina erecta
Convoluceae	Cuscuta spp.
	Ibervillea sonorae
	Ipomoea sp.
	Jacquemontia abutiliodes
	Jaquinia pungens
	Merremia palmeri
Cucurbitaceae	Apodathera undulata
	Cucurbita digitata
	Tumamoca macdougalli
Euphorbiaceae	Acalypha californica
	Chamaesyce polycarpa
	Croton sonorae
	Ditaxis lanceolata
	Ditaxis neomexicana
	Euphorbia florida
	Euphorbia magdalenae
	Euphorbia miseria
	Euphorbia polycarpa
	Euphorbia xantii
	Jatropha cardiophylla
	Jatropha cinerea
	Jatropha cordata
	Jatropha cuneata
	Pedilanthus macrocarpus
	Sapium biloculare
Fabaceae	Acacia angustissima
	Acacia constricta
	Acacia greggii
	Caesalpinia palmeri
	Caesalpinia pannosa
	Caesalpinia pumila
	Calliandra californica
	Coursetia glandulosa
	Dalea spp.
	Desmanthus covillei
	Desmanthus fruticosus
	Hoffmanseggia intricata
	Lupinus arizonicus
	Marina evanescens
	Marina parryi
	Mimosa biuncifera
	Mimosa laxiflora
	Nissolia schottii

Appendix I: Plants Found Under Ironwwood

Family	**Species**
	Olneya tesota
	Parkinsonia floridum
	Parkinsonia microphylla
	Parkinsonia peninsulare
	Phaseolus filiformis
	Pithecellobium confine
	Prosopis glandulosa
	Prosopis velutina
	Psorothamnus emoryi
	Senna covesii
	Tephrosia palmeri
	Vallesia glabra
Fouquieriaceae	Fouquieria columnaris
	Fouquieria diguetii
	Fouquieria splendens
	Fouquieria macdougalli
Hydrophyllaceae	Nama hispidum
	Phacelia ambigua
Kramariaceae	Krameria erecta
	Krameria grayi
Lamiaceae	Hyptis emoryi
	Salvia columbiarae
Loasaceae	Mentzelia adherens
Loranthaceae	Sruthanthus palmeri
	Psitticanthus sonorae
Malpighiaceae	Janusia californica
	Janusia gracilis
	Janusia linearis
	Herissantha crispa
	Mascagnia macroptera
Malvaceae	Abutilon californicum
	Abutilon incanum
	Hibiscus denundatus
	Horsfordia newberryi
	Sphaeralcea ambigua
Nyctaginaceae	Allionia incarnata
	Boerhavia sp.
	Commicarpus scandens
	Mirabilis bigelovii
Onagraceae	Camissonia claviformis
Passifloraceae	Passiflora foetida
Phytolaccaceae	Stegnosperma halmifolium
Plantaginaceae	Plantago insularis
	Plantago purshii
Poaceae	Aristida adscensionis
	Aristida ternipes
	Bouteloua aristidoides
	Digitaria californica

Appendix I: Plants Found Under Ironwwood

Family	Species
	Heteropogon contortus
	Muhlenbergia microsperma
	Muhlenbergia porteri
	Panicum hirticaule
	Pennisetum ciliare
	Setaria liebmanii
	Setaria macrostachya
	Schismus barbatus
	Vulpia sp.
Polygonaceae	Antigonon leptopus
	Chorizanthe sp.
	Eriogonum fasciculatum
	Eriogonum inflatum
	Eriogonum trichopes
	Eriogonum wrightii
	Tephrosia palmeri
Portulaccaceae	Talinum paniculatum
Rhamnaceae	Colubrina glabra
	Colubrina viridis
	Karwinksia parviflora
	Ziziphus obtusifolia
Rubiaceae	Gallium stellatum
	Randia obcordata
Sapindaceae	Cardiospermum corindum
Schrophulariaceae	Castilleja exserta
Simaroubaceae	Castela peninsularis
Simmondsiaceae	Simmondsia chinensis
Solanaceae	Datura discolor
	Lycium andersonii
	Lycium berlandieri
	Lycium exsertum
	Lycium fremontii
	Lycium parishii
	Physalis sp.
	Solanum eleagnifolium
	Solanum hindsianum
Sterculiaceae	Melochia tomentosa
Ulmaceae	Celtis pallida
Umbelliferae	Daucus pusillus
Verbinaceae	Lantana horrida
	Lippia palmeri
Viscaceae	Phoradendron californicum
Zygophyllaceae	Fagonia californica
	Guaiacum coulteri
	Larrea tridentata
	Viscainoa geniculata

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Mammals				
Notiosorex crawfordi	desert shrew	X	R	NRFS
Macrotus californicus	California leaf-nosed bat	X	R*SR	
Choeronycteris mexicana	Mexican long-tongued bat		X	
Euderma maculata	spotted bat		X	
Eumops perotis californicus	greater western mastiff bat		X	
Leptonycteris curasoae	lesser long-nosed bat	X	R*S	
Myotis californicus	Californian myotis		X	
Myotis lucifugus	occult little brown bat		X	
Myotis thysanodes	fringed myotis	X		
Myotis velifer	cave myotis	X		
Myotis yumanensis	Yuma myotis			X
Pipistrellus hesperus	western pipistrelle	X		R
Eptesicus fuscus	big brown bat	X	SR	
Lasiurus blossevillii	western red bat		X	
Lasiurus cinereus	hoary bat		X	
Lasiurus xanthinus	western yellow bat		X	
Corymorhinus townsendii	Townsend's big-eared bat		S	
Antrozous pallidus	pallid bat	X	R*S	
Nyctinomops femorasaccus	pocketed free-tail bat		X	
Nyctinomops macrotis	big free-tailed bat	X		
Tadarida brasiliensis	Mexican free-tailed bat		X	
Sylvigalus audubonii	desert cottontail	X	SNRF	
Lepus allenii	antelope jack rabbit	FRN	SNRF	
Lepus californicus	black-tailed jack rabbit	FRN	SNRF	
Ammospermophilus harrisii	Harris' antelope squirrel	R	SNRF	
Ammospermophilus leucurus	white-tailed antelope squirrel			X
Spermophilus variegatus	rock squirrel	R	SNRF	
Thomomys bottae	Botta's pocket gopher		N	
Spermophilus tereticaudus	round-tailed ground squirrel	R	FSX	NF
Perognathus amplus	Arizona pocket mouse		NF	
Perognathus longimembris	little pocket mouse		NF	
Chaetodipus baileyi	Bailey's pocket mouse			X
Chaetodipus formosus	long-tailed pocket mouse		NF	
Chaetodipus intermedius	rock pocket mouse	R	NF	
Chaetodipus penicillatus	desert pocket mouse	R	NF	
Chaetodipus spinatus	spiny pocket mouse		X	
Dipodomys deserti	desert kangaroo rat	R	NF	
Dipodomys merriami	Merriam's kangaroo rat	R	NF	NF
Dipodomys spectabilis	banner-tailed kangaroo rat			X
Eutamias dorsalis	cliff chipmonk		NFS	
Peromyscus eremicus	cactus mouse	FR	NRF	
Peromyscus maniculatus	deer mouse			X
Peromyscus merriami	mesquite mouse	R		
Onychomys torridus	southern grasshopper mouse		NRF	

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Neotoma albigula	white-throated wood rat	RNF	NRF	
Neotoma lepida	desert wood rat	RNF	NRF	
Reithrodontomys fulvescens	fulvous harvest mouse		X	
Sigmodon ochrognathus	yellow-nosed cotton rat		X	
Canis latrans	coyote	R	NRFS	
Vulpes macroti	kit fox	X		
Vulpes vulpes	red fox			X
Urocyon cinereoargenteus	gray fox	X	NRFS	
Taxidea taxus	badger		NS	N(B)F
Mephitis macroura	hooded skunk		X	
Mephitis mephitis	striped skunk	X		
Spilogale gracilis	western spotted skunk		NS	
Bassaricus astutus	ringtail	X		
Procyon lotor	raccoon	X		
Felis concolor	mountain lion	X	FS	
Felis rufus	bobcat	X	FS	
Tayassu tajacu	collared peccary	FR	FS	
Odocoileus hemionus	mule deer	F	FS	
Odocoileus virginianus	white-tailed deer	F		
Antilocapra americana	pronghorn	F	X	
Ovis canadensis	bighorn	RNF	FX	
Ursus americanus	black bear		X	
Birds				
Ardea herodias	great blue heron			X
Coragyps atratus	black vulture	R	RN	
Cathartes aura	turkey vulture	R	RN	
Pandion haliaetus	osprey	R		
Ictinia mississippiensis	Mississippi kite		X	
Haliaeetus leucocephalus	bald eagle			X
Circus cyaneus	northern harrier		NRS	
Accipiter cooperii	Cooper's hawk		NRS	
Accipiter gentilis	northern goshawk			X
Accipiter striatus	sharp-shinned hawk			X
Parabuteo unicinctus	Harris' hawk	RN	NRS	
Buteo albonotatus	zone-tailed hawk		X	
Buteo jamaicensis	red-tailed hawk	RN	NRS	
Buteo nitidus	northern grey hawk		X	
Buteo swainsoni	Swainson's hawk		X	
Aquila chrysaetos	golden eagle	R	NRS	
Caracara plancus	crested caracara	RN	NRS	
Falco columbarius	merlin			X
Falco mexicanus	prairie falcon		RS	
Falco peregrinus	peregrine falcon			X
Falco sparverius	American kestrel	R	NRS	
Colinus virginianus	northern (masked) bobwhite		X	
Callipepla californica	California quail	X		
Callipepla douglasii	elegant quail	X		

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Callipepla gambelii	Gambel's quail	NR	RFS	N
Columba livia	rock dove		NRSF	X
Zenaida asiatica	white-winged dove	RN	NRSF	
Zenaida macroura	mourning dove	RN	NRSF	
Columbina inca	inca dove	RN	NRSF	
Columbina passerina	common ground-dove	RN	NRSF	X
Geococcyx californianus	greater roadrunner	R	NRSF	
Coccyzus americanus	yellow-billed cuckoo			X
Tyto alba	barn owl		RSN	
Otus kennicottii	western screech-owl	PXR	NRSF	
Asio otus	long-eared owl		X	
Bubo virginianus	great horned owl	X	NRSF	
Glacidium brasilianum	ferruginous pygmy-owl	XR	NRSF	
Micrathene whitneyi	elf owl	XP	RFS	N
Speotyto cunicularia	burrowing owl			X
Chordeiles acutipennis	lesser nighthawk	X	N	
Phalaenoptilus nuttallii	common poorwill	X	N	
Caprimulgus ridgwayi	buff-collared nightjar		N	
Caprimulgus vociferus	whip-poor-will			X
Aeronautes saxatalis	white-throated swift	X		
Cynanthus latirostris	broad-billed hummingbird		PX	
Archilochus alexandri	black-chinned hummingbird		X	
Calothorax lucifer	lucifer hummingbird			X
Calypte anna	Anna's hummingbird	R	XN	
Calypte costae	Costa's hummingbird	PX		F
Selasphorus platycercus	broad-tailed hummingbird			X
Selasphorus rufus	rufous hummingbird	P	X	
Selasphorus sasin	Allen's hummingbird			X
Stellula calliope	calliope hummingbird			X
Trogon elegans	elegant trogon			X?
Ceryle alcyon	belted kingfisher			X
Melanerpes formicivorus	acorn woodpecker			X
Melanerpes uropygialis	gila woodpecker	X	PFSRN	
Sphyrapicus nuchalis	red-naped sapsucker		X	X
Picoides scalaris	ladder-backed woopecker	X	PN	
Picoides stricklandi	Strickland's woodpecker			X?
Colaptes auratus	northern flicker			X
Colaptes chrysoides	gilded flicker	R	FSRN	
Camptostoma imberbe	northern beardless-tyrannulet			X
Empidonax difficilis	pacific-slope flycatcher			X
Empidonax minimus	least flycatcher			X
Empidonax oberholseri	dusky flycatcher			X
Empidonax occidentalis	Cordelleran flycatcher			X
Empidonax traillii	willow flycatcher			X
Empidonax wrightii	gray flycatcher			X
Sayornis nigricans	black phoebe			X
Sayornis saya	Say's phoebe			X

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Pyrocephalus rubinus	vermillion flycatcher			XN
Myiarchus cinerascens	ash-throated flycatcher	P	N	
Myiarchus tyrannulus	brown-crested flycatcher	X	PN	
Tyrannus melancholicus	tropical kingbird		X	
Tyrannus verticalis	western kingbird	R	FRSN	
Tyrannus vociferans	Cassin's kingbird	X		
Eremophila alpestris	horned lark			X
Progne subis	purple martin	X	N	
Tachycineta bicolor	tree swallow			X
Tachycineta thalassina	violet-green swallow			X
Stelgidopteryx serripennis	northern rough-winged swallow	?		X
Riparia riparia	bank swallow			X
Hirundo pyrrhonota	cliff swallow			X
Hirundo rustica	barn swallow			X
Aphelocoma coerulescens	scrub jay		X	
Corvus corax	common raven	X	N	
Corvus cryptoleucus	Chihuahuan raven	R	FRS	
Parus wollweberi	bridled titmouse		N	
Auriparus flaviceps	verdin	NX		
Campylorhynchus brunneicapillus	cactus wren	R	PFNRS	
Salpinctes obsoletus	rock wren	X	N	
Catherpes mexicanus	canyon wren	X	N	
Thryomanes bewickii	Bewick's wren			XN
Troglodytes aedon	house wren			X
Regulus calendula	ruby-crowned kinglet	R	X	
Polioptila caerulea	blue-gray gnatcatcher		FRSN	X
Polioptila melanura	black-tailed gnatcatcher	R	FRSN	
Polioptila nigriceps	black -capped gnatcatcher		N	
Myadestes townsendi	Townsend's solitaire			X
Catharus guttatus	hermit thrush			X
Catharus ustulatus	Swainson's thrush			X
Turdus migratorius	American robin			X
Mimus polyglottos	northern mockingbird	RN	PFRNS	
Toxostoma bendirei	Bendire's thrasher			X
Toxostoma cinereum	gray thrasher	X?		
Toxostoma crissale	crissal thrasher	RN		X
Toxostoma curvirostre	curve-billed thrasher	RN	P	
Toxostoma lecontei	Le Conte's thrasher			X
Bombycilla cedrorum	cedar waxwing			X
Phainopepla nitens	phainopepla	RN	P	
Lanius ludovicianus	loggerhead shrike	R	FRSN	X
Sturnus vulgaris	European starling	R	N	X
Vireo bellii	Bell's vireo		N	X
Vireo gilvus	warbling vireo			X
Vireo huttoni	Hutton's vireo			X
Vireo solitarius	solitary vireo			X

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Vireo vicinior	gray vireo			X
Vermivora celata	orange-crowned warbler		F	X
Vermivora luciae	Lucy's warbler		N	X
Vermivora ruficapilla	Nashville warbler		F	X
Vermivora virginiae	Virginia's warbler			X
Dendroica coronata	yellow-rumped warbler			X
Dendroica nigrescens	black-throated gray warbler			X
Dendroica occidentalis	hermit warbler			X
Dendroica petechia	yellow warbler			X
Dendroica townsendi	Townsend's warbler		F	X
Oporornis tolmiei	Macgillivray's warbler			X
Geothlypis trichas	common yellowthroat			X
Wilsonia pusilla	Wilson's warbler	X?	FRS	X
Piranga ludoviciana	western tanager			X
Piranga rubra	summer tanager			X
Cardinalis cardinalis	northern cardinal	XNR	PX	
Cardinalis sinuatus	pyrrhuloxia	XNR	FRS	
Pheucticus melanocephalus	black-headed grosbeak		P	X
Guiraca caerulea	blue grosbeak			X
Passerina amoena	lazuli bunting			X
Passerina ciris	painted bunting			X
Passerina versicolor	varied bunting	XN		
Pipilo aberti	Abert's towhee			X
Pipilo chlorurus	green-tailed towhee		X	
Pipilo fuscus	canyon towhee	XN		
Pipilo maculatus	spotted towhee		X	
Aimophila carpalis	rufous-winged sparrow			XN
Aimophila ruficeps	rufous-crowned sparrow		X	
Spizella atrogularis	black-chinned sparrow		X	
Spizella breweri	Brewer's sparrow		X	
Spizella passerina	chipping sparrow		X	
Amphispiza bilineata	black-throated sparrow	X	FRSN	
Calamospiza melanocorys	lark bunting			X
Passerculus sandwichensis	savannah sparrow			X
Melospiza lincolnii	Lincoln's sparrow			X
Melospiza melodia	song sparrow			X
Zonotrichia leucophyrys	white-crowned sparrow	R		X
Junco hyemalis	dark-eyed junco			X
Agelaius phoeniceus	red-winged blackbird			X
Sturnella neglecta	western meadowlark			X
Xanthocephalus xanthocephalus	yellow-headed blackbird			RS
Quiscalus mexicanus	great-tailed grackle			X
Molothrus aeneus	bronzed cowbird			XN
Molothrus ater	brown-headed cowbird	XN		
Icterus cucullatus	hooded oriole	R	N	X
Icterus parisorum	Scott's oriole		N	
Carpodacus mexicanus	house finch	X	PNFSR	

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Carduelis lawrencei	Lawrence's goldfinch			X
Carduelis pinus	pine siskin			X
Carduelis psaltria	lesser goldfinch			X
Passer domesticus	house sparrow		NFSR	X
Reptiles and Amphibians				
Kinosternon flavescens	mud turtle			X
Kinosternon flavescens arizonense	southwest mud turtle			SN*
Kinosternon sonoriense	Sonoran mud turtle			SN*
Gopherus agassizii	desert tortoise	FRN	NFSR	
Coleonyx variegatus	western banded gecko		NFR	
Phyllodactyluus homolepidurus	leaf-toed gecko			NR
Xantusia vigilis	desert night lizard	RN		NFR
Callisaurus draconoides	zebra-tailed lizard	RN	FRS	
Crotaphytus nebrius	Sonoran collared lizard	RN	NFS	
Crotaphytus dickersonae	collared lizard	RN		X
Ctenosaura conspicuosa	spiny-tailed iguana	F?RN	FRS	
Dipsosaurus dorsalis	desert iguana	RN	NFSR	
Holbrookia maculata	lesser earless lizard	RN	NFS	
Uma notata	Colorado desert fringe-toed lizard			RS
Uma scoparia	Mojave fringe-toed lizard			RS
Gambelia wislizenii	leopard lizard			FRN
Phrynosoma solare	regal horned lizard			FRN
Phrynosoma mcallii	flat-nosed horned lizard			X
Phrynosoma platyrhinos	desert horned lizard			FRN
Phrynosoma mcallii	flat-tailed horned lizard			X
Sauromalus obesus	chuckwalla			F
Sauromalus varius	San Esteban/piebald chuckwalla	F		
Sauromalus hispidus	black chuckwalla	F?		
Sceloporus clarkii	Clark's spiny		R	RNF
Sceloporus magister	desert spiny	RNFS	X	
Urosaurus graciosus	long-tailed brush lizard	RNFS		
Urosaurus ornatus	tree lizard	RNFS	X	
Uta stansburiana	side blotched lizard	RNFS		
Cnemidophorus burtii	whiptail		RNFS	
Cnemidophorus tigris	western whiptail	RNFS		
Heloderma suspectum	Gila monster	RNFS		
Eumeces gilberti	red-tailed skink		X	
Boa constrictor	boa			FS
Charina trivirgata	rosy boa		RNFS	
Chilomeniscus cinctus	banded sand snake			RN(B)
Chilomeniscus stramineus	banded & bandless sand snake			RNFS

Appendix II: Animals in xeroriparian areas of the Sonoran Desert Region

SPECIES	Common Names	Regular Users	Occasional Users	Infrequent/ Anomalous Users
Chionactis occipitalis	Western shovel-nosed snake			X
Chionactis palarostris	shovelnose snake		X	
Hypsiglena torquata	night snake			RNFS
Arizona elegans	glossy snake	X		RNFS
Lampropeltis getula	common kingsnake		RNFS	
Masticophis bilineatus	Sonoran whipsnake		RNFS	R
Masticophis flagellum	coachwhip		RNFS	R
Oxybelis aeneus	brown vine snake			RNFS
Phyllorhynchus brownii	Maricopa leafnose snake		RNFS	
Pituophis melanoleucus	gopher snake		X	
Rhinocheilus lecontei	long-nosed snake		X	
Tantilla hebartsmithi	southwestern black-headed snake			N(B)
Micruroides euryxanthus	western coral snake		X	
Crotalus atrox	western diamondback	F	SN	
Crotalus cerastes	sidewinder	X		F
Crotalus estebanensis	San Esteban rattlesnake			X
Crotalus molossus	black-tailed rattlesnake		F	
Crotalus mitchelli	speckled rattlesnake		X	
Crotalus tigris	tiger rattlesnake		F	
Crotalus scutulatus	Mohave rattlesnake			F
Bufo alvarius	Sonoran desert toad		F	
Bufo cognatus	great plains toad		F	
Bufo debilis	western green toad		X	
Bufo microscaphus	Arizona toad		X	
Bufo punctatus	red-spotted toad		F	
Bufo retiformis	Sonoran green toad		F	
Gastrophryne olivacea	great plains narrowmouth toad		X	
Rana yavapaiensis	lowland leopard frog			X
Scaphiopus couchi	Couch's spadefoot		F	
Spea multiplicata	southern spadefoot		F	

X= Present
N= Nesting in trees or burrowing under trees
R= Roosting or refuge sites
S= Resting in shade
P= Perching
F= Forage/food use of pods, flowers, or leaves

* only associated with ironwood at ponds or streams through ironwood habitat

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	Common Names	United States	Mexico	Pima County	Arizona Native Plant	CITES
Plants						
Bursera microphylla	elephant tree, torote				salvage restricted	
Carnegiea gigantea	saguaro, sahuaro				salvage restricted	seeds
Echinocereus fendleri robustus	pinkflower hedgehog cactus					seeds
Echinomastus erectocentrus	acuna cactus	candidate for endangered			highly safeguarded, salvage restricted	seeds
Ferocactus cylindraceus var cylindraceus	mountain barrel cactus, biznaga					seeds
Ferocactus diguetii	barrel cactus, biznaga					seeds
Ferocactus emoryi	barrel cactus, biznaga				salvage restricted	seeds
Ferocactus wislizenii	barrel cactus, biznaga				salvage restricted	seeds
Fouquieria columnaris	boojum, cirio					listed
Fouquieria splendens	ocotillo				salvage restricted	
Guaiacum coulteri			Sujeta a proteccion especial			
Lophocereus schottii	senita, sinita					seeds
Mammillaria grahamii	Graham's fishhook cactus				salvage restricted	seeds
Mammillaria mainae					salvage restricted	seeds
Mammillaria tetrancistra	corkseed fishhook cactus				salvage restricted	seeds
Mammillaria thornberi	fishhook cactus				salvage restricted	seeds
Olneya tesota	desert ironwood, palo fierro		Sujeta a proteccion especial	keystone species	harvest restricted	
Opuntia acanthocarpa	buckhorn cholla, cholla				salvage restricted	seeds
Opuntia arbuscula	pencil cholla, siviri				salvage restricted	seeds
Opuntia bigelovii	teddy-bear cholla				salvage restricted	seeds
Opuntia ciribe						seeds
Opuntia fulgida fulgida	jumping cholla, cholla				salvage restricted	seeds
Opuntia fulgida mammillata					salvage restricted	seeds
Opuntia leptocaulis	desert Christmas cactus, tasajillo				salvage restricted	seeds
Opuntia phaecantha/engelmanii	desert prickly pear, nopal				salvage restricted	seeds

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	Common Names	United States	Mexico	Pima County	Arizona Native Plant	CITES
Opuntia violacea	Santa Rita prickly pear					seeds
Pachycereus pringlei	cardon					seeds
Parkinsonia floridum	blue palo verde				salvage assessed	
Parkinsonia microphylla	foothill palo verde				salvage assessed	
Peniocereus greggii	desert night-blooming cereus, reina de la noche					seeds
Peniocereus striatus	dahlia rooted cereus, sacamatraca			at risk in county		seeds
Prosopis glandulosa	honey mesquite, mezquite			salvage assessed, harvest restricted		
Prosopis velutina	velvet mesquite, mezquite			salvage assessed, harvest restricted		
Sapium biloculare	Mexican jumping bean				salvage restricted	
Stenocereus gummosus	pitahaya agria					seeds
Stenocereus thurberi	organ pipe cactus, pitahaya dulce				salvage restricted	seeds
Mammals						
Notiosorex crawfordi crawfordi	desert shrew		amenazada			
Euderma maculata	spotted bat		rara			
Leptonycteris curasoae yerbabuenae	lesser long-nosed bat	endangered, sensitive (Regional Forester), Wildlife of special concern (AGFD)	amenazada	declining		
Lepus californicus shelderi			rara			
Lepis allenii tiburonensis			rara			
Perognathus penillatus seri			amenazada			
Perognathus spinatus guardiae			amenazada			

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	Common Names	United States	Mexico	Pima County	Arizona Native Plant	CITES
Peromyscus eremicus tiburonensis			amenazada			
Peromyscus guardii			en peligro de extincion			
Peromyscus merriami	mesquite mouse			declining		
Neotoma albigula seri			amenazada			
Felis concolor	mountain lion	threatened				
Antilocapra americana	pronghorn	endangered	en peligro de extinccion			
Ovis canadensis	bighorn		sujeta a proteccion especial			
Birds						
Haliaeetus leucocephalus	bald eagle	threatened, sensitive (Regional Forester), Wildlife of special concern (AGFD), Navajo Endangered Species List (status 3)		rare in county		
Parabuteo unicinctus	Harris' hawk, aguililla rojinegra	sensitive (Regional Forester)	amenazada	at risk in county		
Buteo nitidus	grey hawk	Species of Concern (USFWS), sensitive (Regional Forester), Wildlife of special concern (AGFD)		at risk in county		
Buteo swainsoni	Swainson's hawk	sensitive (Regional Forester)		declining		
Buteo albonotatus	zone-tailed hawk	sensitive-Regional Forester, Navajo Endangered Species list status 1		at risk in county		
Buteo jamaicensis	red-tailed hawk		sujeta a proteccion especial			
Aquila chrysaetos	golden eagle, aguila real		en peligro de extincion			

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	Common Names	United States	Mexico	Pima County	Arizona Native Plant	CITES
Caracara plancus	crested caracara	sensitive (Regional Forester), Wildlife of Special Concern (AGFD)		at risk in county		
Falco columbarius	merlin, halcon esmerejon		amenazada			
Falco mexicanus	prairie falcon, halcon mexicano		amenazada			
Falco peregrinus	peregrine falcon, halcon peregrino	endangered, sensitive (Regional Forester), Wildlife of Special Concern (AGFD, Navajo Endangered Species List	amenazada	rare in county		
Colinis virginianus ridgwayi	masked bobwhite	endangered		crucial		
Bubo virginianus	great horned owl, bujo cornudo		amenazada	keystone predator		
Glaucidium brasilianum cactorum	ferruginous pygmy-owl, tecolote bajen~o	endangered	amenazada	crucial		
Micrathene whitneyi	elf owl					
Speotyto cunicularia	burrowing owl		amenazada	declining		
Caprimulgus ridgwayi	buff-collared nightjar	sensitive (Regional Forester)		at risk in county		
Trogon elegans	elegant trogon			at risk in county		
Empidonax traillii extimus	southern willow flycatcher	endangered		declining		
Progne subis	purple martin			at risk in county		
Toxostoma lecontei	Le Conte's thrasher			declining		
Vireo bellii	Bell's vireo			declining		
Reptiles and Amphibians						
Gopherus agassizii	desert tortoise	threatened	amenazada			
Coleonyx variegatus	western banded gecko		rara			
Phyllodactyluus homolepidurus	leaf-toed gecko		rara			
Xantusia vigilis	desert night lizard					

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	**Common Names**	**United States**	**Mexico**	**Pima County**	**Arizona Native Plant**	**CITES**
Callisaurus draconoides	zebra-tailed lizard		amenazada			
Crotaphytus nebrius	Sonoran collared lizard					
Crotaphytus dickersonae	collared lizard		amenazada			
Ctenosaura hemophila	spiny-tailed iguana		sujeta a proteccion especial	pest species		
Gambelia wislizenii	leopard lizard		rara			
Sauromalus obesus			amenazada			
Sauromalus varius	San Esteban/piebald chuckwalla		amenazada			
Sauromalus hispidus	black chuckwalla		amenazada			
Cnemidophorus burtii strictogrammus	giant spotted whiptail	USFWS -species of concern		declining		
Cnemidophorus burtii xanthonotus	red-backed whiptail lizard	USFWS -species of concern		crucial		
Cnemidophorus stebanensis			rara			
Cnemidophorus tigris	western whiptail					
Heloderma suspectum	Gila monster		amenazada			
Eumeces gilberti	red-tailed skink		rara			
Chilomeniscus cinctus	banded sand snake		rara			
Chilomeniscus stramineus	banded & bandless sand snake		rara			
Hypsiglena torquata	night snake		rara			
Lampropeltis getula	common kingsnake		amenazada			
Lampropeltis getula nigrita	black kingsnake			at risk in county		
Masticophis bilineatus	Sonoran whipsnake		amenazada			
Masticophis flagellum	coachwhip		amenazada			
Micruroides euryxanthus	western coral snake		amenazada			
Crotalus atrox	western diamondback		sujeta a proteccion especial			
Crotalus cerastes	sidewinder		sujeta a proteccion especial			

Appendix III- Xeroriparian species listed internationally, federally, statewide, and countywide as important species

SPECIES	Common Names	United States	Mexico	Pima County	Arizona Native Plant	CITES
Crotalus molossus	black-tailed rattlesnake		sujeta a proteccion especial			
Crotalus mitchelli			sujeta a proteccion especial			
Crotalus ruber			sujeta a proteccion especial			
Crotalus tigris	tiger rattlesnake		sujeta a proteccion especial			
Rana yavapaiensis	lowland leopard frog	species of concern (USFWS), sensitive (Regional Forester), Wildlife of special concern (AGFD)		declining		

Appendix IV: Pollinators and Nurse Plant Habitat Datasheet

Plot Number (also tag number)__________________________ **Date** ______________________ Photo taken Y or N

Center point marked with rebar ? (Y or N)_____ **Plot Size** (circle one): **12.6m radius** or **8.9m radius**

Recorder(s) ______________________________**Phone Number(s)**____
Affiliation:____

UTMs:(Preferred)___________________________(easting)________________________________(northing)

(If Necessary) Lat______________________________ Long___________________________________

UTM Method (circle one): 1-GPS w/differential 2-GPS w/o differential 3-Map
Datum (circle one): NAD 27 NAD 83 WGS 84(preferred)

***State** (circle one):
1-Arizona
2-Southern California
3-Sonora
4-Baja California Sur
5-Baja California Norte

***Ownership** (circle all that apply):
1-Bureau of Land Management
2-Bureau of Reclamation
3-National Forest Service
4-National Park Service
5-National Wildlife Refuge
6- SEMARNAP reserve
7-Tribal
8-State
9-Private
10-Multiple owners
11-Ejido
12-County parkland
13-Other/unknown

INEGI/USGS Quad. Name: ____
Elevation: __________ METERS
Elevation Method: (circle one) 1-GPS 2-Altimeter 3-Map 4-Estimate

Directions from nearest landmark or town:

Nurse Plant Centered (N) or Random (R) ______________ Nurse Plant Species_________________________________
Cutting evident (Y or N)______ If yes is cutting at the base_________ on lateral branches_______ or other level ___________
How many stems at base? _________ mean basal diameter_______________
Canopy Area of Central Tree: NS diameter _______m. EW diameter_______m. Basal Diameter of the largest trunk_________

Slope ______________________ (degrees) Aspect N S E W NE NW SE SW

Landforms (please circle all that apply)	**Uses observed onsite (please circle all that apply)**
A. Ephemeral watercourse B. Intermittent watercourse C. Perennial watercourse D. Floodplain alluvium E. Valleys/plains alluvium F. Rocky slope G. Mesa or ridgetop H. Below cave mouth I. Other ________	A. Cattle grazing B. Goat grazing C. Chainsaw woodcutting D. Ax woodcutting E. ORV tracks F. Medicinal plant harvesting G. Garbage dumping H. Irrigation tailwater/stormwater drainage I. Burned J. Other ____________________ K. None

Associated Vegetation (circle all that apply):

A. Arizona Uplands
B. Lower Colorado
C. Plains of Sonora
D. Central Gulf Coast
E. Coastal Thornscrub
F. Foothills Thornscrub
G. Tropical Deciduous Forest
H. Abandoned cropland
I. Riparian gallery forest
J. Riparian scrub/bosque
K. Other ______________________

Plant Species Present

Perennial Species (use separate row for the species under cover of Nurse plants)	N	Log2 N	x̄ diam.	Log2 C	Log2N + Log2C	Non-native?	Nurse plant	Phen

Annuals: please circle those species that are under the nurse plant on nurse-plant centered plots:

Description of multiple levels of canopies:

Appendix V: Ironwood Midden Records

Tom Van Devender

Hornaday Mountains, Sonora

Olneya tesota was found in six middens at 240 m elevation in the Hornaday Mountains, Pinacate Region, northwestern Sonora. The oldest is from a sample radiocarbon dated at 8660 yr B.P. (radiocarbon years before 1950) in the latest early Holocene or middle Holocene. The other five middens with *Olneya tesota* ranged from 4430 to 1720 yr B.P. in the late Holocene.

Van Devender, T. R., T. L. Burgess, R. S. Felger, and R. M. Turner. 1990. Holocene vegetation of the Hornaday Mountains of northwestern Sonora, Mexico. Proceedings of the San Diego Natrural History Museum, Number 2, 19 pp.

Picacho Peak, California

Olneya tesota was found in a single 110 yr B.P. sample at 240 - 300 m elevation in the Picacho Peak, Imperial County, California. It was absent from 22 samples dated from 12,730 to 630 yr B.P. (Cole 1986).

Cole, K. L. 1986. The lower Colorado Valley: a Pleistocene desert. Quaternary Research 25:392-400.

Butler Mountains, Arizona

Olneya tesota was found in middens dated at 7530, 3820, and 740 yr B.P. at 245-255 m elevation inthe granitic Butler Mountains on the western base of the Tinajas Altas Mountains, Yuma County, Arizona (T. R. Van Devender, unpubl. data). It was absent from four samples dated from 11250 to 8160 yr B.P.

Tinajas Altas Mountains

Olneya tesota was found in six middens at 365 to 580 m elevation in the granitic Tinajas Altas Mountains, Yuma County, Arizona (Van Devender 1990). Two early-middle samples dated at 9900 and 8700 yr B.P. were possible contaminants. Four other samples dated from 6220 to 1230 yr B.P.

Van Devender, T. R. 1990. Late Quaternary vegetation and climate of the Sonoran Desert, United States and Mexico. Pp.134-164 *in* J. L. Betancourt, T. R. Van Devender, and P. S. Martin (eds.) Packrat Middens. The Last 40,000 Years of Biotic Change. Universitry of Arizona Press, Tucson.

Wellton Hills, Arizona

Olneya tesota was found at 160 m elevation in a midden dated at 8750 yr B.P. in the Wellton Hills, just south of the Gila River in Yuma County, Arizona (T. R. Van Devender Unpubl. data). It was absent from samples dated at 10750, 8150, and 3520 yr B.P.

Puerto Blanco Mountains

In the Puerto Blanco Mountains of Organpipe Cactus National Monument, Pima County, Arizona, *Olneya tesota* was found in ten middle and late Holocene middens dated from 7580 to 1910 yr B.P. from 535 to 605 m elevation (Van Devender 1987).

Van Devender, T. R. 1987. Holocene vegetation and climate in the Puerto Blanco Mountains, southwestern Arizona. Quaternary Research 27:51-72.

Waterman Mountains, Arizona

Olneya tesota was found in three middens at 795 m elevation in the limestone Waterman Mountains, Pima County, Arizona (Anderson and Van Devender 1991). A few leaflets and thorns in a sample dated at 8310 yr B.P. were thought to be contaminants. It was common in late Holocene samples dated at 1320 and 1200 yr B.P. It was absent from 14 samples dating from 22450 to 2600 yr B.P.

Anderson, R. S., and T. R. Van Devender. 1991. Comparison of pollen and macrofossils in packrat middens (*Neotoma*) middens: a chronological sequence from the Waterman Mountains of southern Arizona, U.S.A. Review of Palaeobotany and Palynology 68:1-28.