ARID LANDS NEWSLETTER

Spring/Summer 1992
Volume 32

BIOREMEDIATION AND ECOLOGICAL RESTORATION

Office of Arid Lands Studies

The University of Arizona
Tucson Arizona

Editor's Note

John M. Bancroft

As the latest in a line of distinguished editors of the *Arid Lands Newsletter* (The jury has yet to consider the evidence in my own case, of course, but the verdict is in on my predecessors.), I am pleased to have the opportunity to introduce this issue on the closely related themes of bioremediation and environmental restoration.

Aside from comprising a growth industry for the coming decade and beyond, these linked endeavors offer great promise for putting right the environmental wrong we have done over the past century.

Kenny Ausubel, a journalist turned environmental entrepreneur, leads off this issue with an overview of the theory behind constructed wetlands and a quick look at the success of Pintail Marsh in Arizona's White Mountains. **John G. Wolan**, an engineer, expands on the technology involved in building and operating a constructed wetland in his article on Jacques Marsh. **Martin M. Karpiscak** and his colleagues at the Office of Arid Lands Studies lay a scientific floor under these two short articles with an in-depth look at a pilot project using water hyacinths to bring treated effluent to tertiary standards in a large metropolitan area.

We move next to the challenge of restoring a degraded environment to health.

Holly E. Richter, an ecologist, draws on her experience at The Nature Conservancy's Hassayampa River Preserve in Arizona to explain the role of a conceptual model in floodplain restoration. **Kristine B. Crandall**, an agricultural economist, uses the same preserve as a case study in how to place an economic value on the pleasures and benefits of a restored desert riparian environment.

Dan James, who for 12 years has helped his company repair the damage caused by construction, mining, and overgrazing in the Sonoran Desert, takes us onto dry land with his article on techniques for revegetating disturbed sites. **Matthew B. Johnson**, a horticulturist, wraps up with a survey of tree legumes from around the world appropriate for use in afforestation and reforestation of dry lands.

In our back pages you'll find a roundup of news from arid lands botanical gardens in Australia, England, and the U.S., together with notices of books, maps, and periodicals of interest to dwellers in dry places.

What you won't find is a repeat of the survey form that occupied the last page of the Fall/Winter 1991 issue—which is not to say that we are no longer interested in hearing from our readers. We learned a lot from those of you who took the time to return the questionnaire, and prospects for *ALN*'s longevity were much improved by those who accepted our invitation to contribute to the *Patricia Paylore Fund for the Arid Lands Newsletter*; all of you have our thanks and our sincere appreciation.

Owing to a delay in mailing the last issue, particularly to international addresses, we realize that some of our readers were unable to meet the January 31 deadline for returning the questionnaire. It's not too late to respond. You can continue as a subscriber in good standing by returning the survey form by **September 1, 1992**. And we are always pleased to receive contributions to the Paylore Fund.

Send completed questionnaires (and all other correspondence, manuscripts, and queries) to:

The Editor
Arid Lands Newsletter
Office of Arid Lands Studies
The University of Arizona
845 North Park Avenue
Tucson, Arizona 85719 USA

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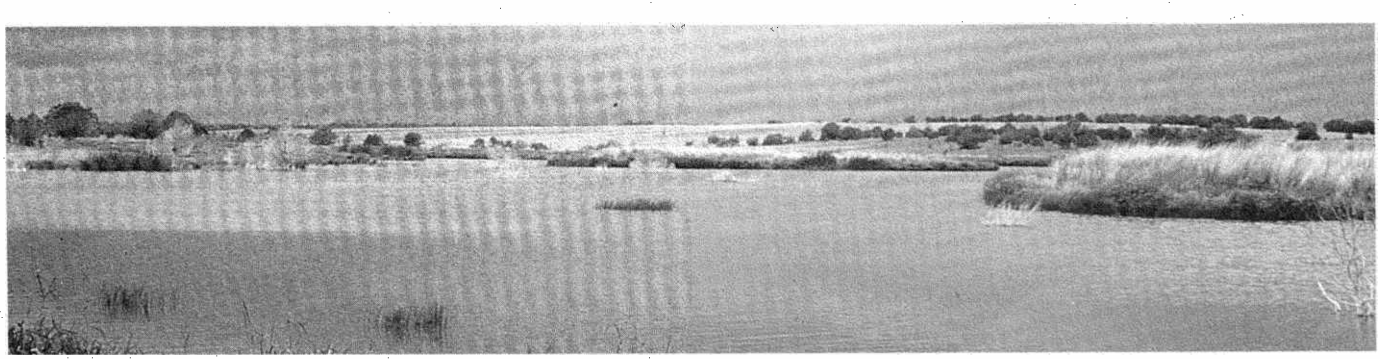

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Editor
John M. Bancroft

Design
Diedre L. Muns
with assistance from
Eliza Cain

Circulation
Ingrid Cardon Downey

Publisher
Office of Arid Lands Studies
College of Agriculture
The University of Arizona
T[illegible]n, Arizona 85719 USA

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We'd like to hear from you. Address letters of comment, requests for future mailing, and items about projects that may be of interest to our readers to:

Editor, *Arid Lands Newsletter*
Office of Arid Lands Studies
University of Arizona
845 North Park Avenue
Tucson, Arizona 85719 USA

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On the cover: Pintail Marsh, a constructed wetland in Arizona's White Mountains.

Cleopatra's Bathwater: An Informal Introduction to the Art and Science of Bioremediation

Kenny Ausubel

The Earth is, in essence, a closed loop, meaning that the stuff of life that is here today most likely was here yesterday, too. The cup of tea you're sipping as you read this, in fact, might once have been Cleopatra's bathwater.

In the final decade of the twentieth century, however, Cleopatra probably would be advised by her counselors to first send to the lab any water in which she planned to bathe. And the lab likely would find a witch's brew of noxious residues ranging from PCBs to pesticides, heavy metals, phosphates, and nitrates—the waste products of an industrial society.

Clean water, some say, will be the oil of the 1990s, and cleaning up the environment is beginning to show signs of displacing weapons production as a growth industry. The question is this: How do we go about this monumental cleanup, and at what cost?

Prior efforts to decontaminate the environment using conventional high technologies have been only partially successful yet hugely expensive. Like bone marrow transplants, environmental high technology is neither designed nor priced to be commonly available. Because the companies that promote such technologies derive much of their profit from costly hardware and complex mechanical systems, they have little economic incentive to seek simpler, cheaper alternatives.

Everything in nature is someone's lunch, and one organism's poison is another's food. Bioremediation, therefore, becomes a game of mixing and matching organisms to digest a particular 'waste,' thereby transforming that waste into a resource.

Fortunately, a relatively simple, low-cost alternative biotechnology has shown its ability to restore the environment. Bioremediation, the use of natural treatment systems to digest wastes, is operating now on every continent but Antarctica, performing water purification tasks at about half the cost of conventional technology. What's more, bioremediation is a technology that introduces no additional chemicals or toxics into the environment it is designed to clean up.

Bioremediation technologies are biomorphic; that is, they imitate nature's cleansing processes. Because nature is a complex web of interdependent relationships not readily analyzed in isolation, simulating natural ecosystems has proven to be the surest way to replicate natural cleansing processes. Nature has no waste; everything is either a nutrient or an energy source. In short, everything in nature is someone's lunch, and one organism's poison is another's food. Bioremediation, therefore, becomes a game of mixing and matching organisms to digest a particular "waste," thereby transforming that waste into a resource.

Natural wetlands long have served as nature's primary water filters. Unfortunately, the growth of human populations has steadily overloaded these natural systems, while at the same time encroaching human development has diminished them. In the United States, for example, only 3 percent of the country's original natural wetlands have survived. There now is hope, however, that biotechnology can help reverse that destructive trend.

Constructed wetlands are gaining favor worldwide as effective, economical systems of wastewater treatment. Constructed wetlands are treating municipal wastewater, acid mine drainage from coal mining, chemical row-crop runoff, agricultural animal wastes, pulp mill wastes, and a variety of other industrial waste products. But their usefulness does not end there. Constructed wetlands also provide ancillary benefits as wildlife habitat, recreation areas, and aesthetic green zones.

If you happen to find yourself in the neighborhood of Arizona's White Mountains, you might want to pack a picnic lunch and explore the Pintail Marsh (and sewage treatment facility) in the Apache-Sitgreaves National Forest near Showlow. The constructed wetland there—the largest in the United States—is successfully treating secondary effluent from neighboring municipalities and then using the effluent to create splendidly productive bird and wildlife habitat.

Pintail, the result of collaboration among municipalities, the USDA Forest Service, and the Arizona Game and Fish Department, transformed a semiarid pinyon-juniper system into one of the wettest places in a dry land.

As Forest Service biologist Mel Wilhelm observed, "You just add water to Arizona and you get riparian."

The constructed system is a good example of what some have come to call eco-nomics. "The bottom line for the cities—why they got into this wetlands concept—was economics," according to Wilhelm. "They had a 37 percent saving in total construction costs (over conventional technology) and a 47 percent saving in annual operating costs."

The Pintail Marsh has been so successful since its inception in 1979 that the nearby towns of Springerville and

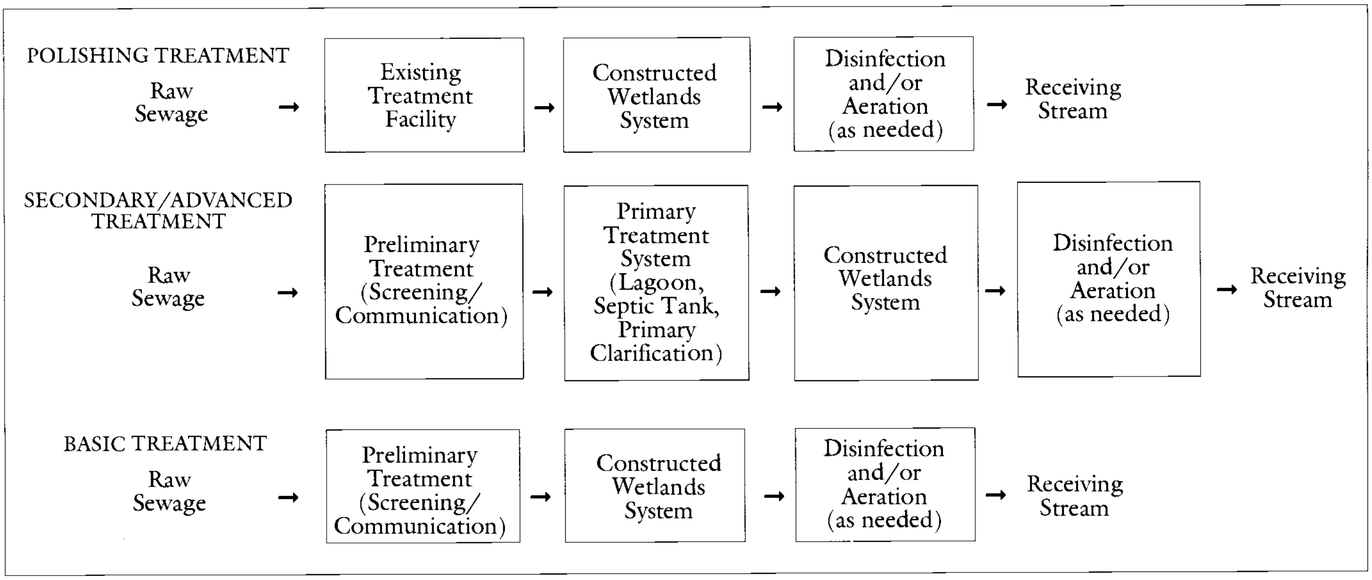

Figure 1. Three of the possible ways in which constructed wetlands can be used in wastewater treatment. Polishing is the function of Pintail Marsh.

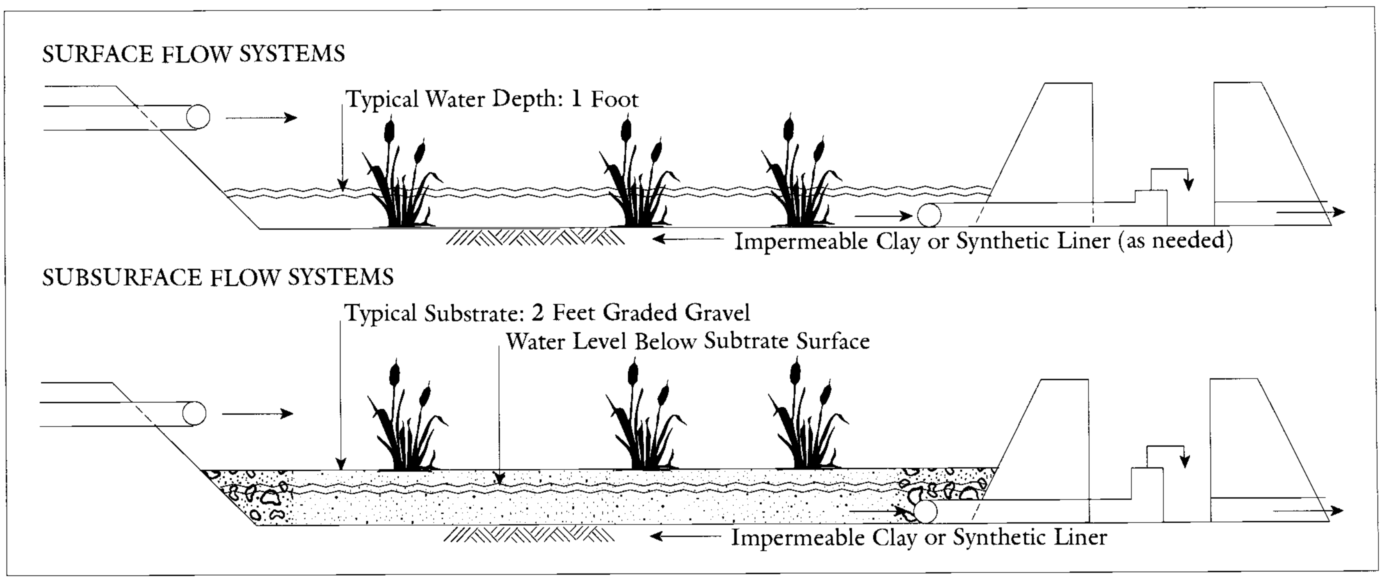

Figure 2. Two of the possible types of constructed wetlands. There are many other possibilities.

Pinetop-Lakeside have followed its example (see "The Creation and Evolution of Jacques Marsh" in this issue for details), bringing to 279 the total regional acreage developed as constructed wetlands.

Constructed wetlands have proven themselves to be the optimal method for tertiary, or "polishing," treatment, the final step in producing clean water and one that is expensive in conventional systems, which require costly chemical or mechanical operations and large engineering budgets. A constructed wetland, on the other hand, relies on the expertise of "bioneers," biological engineers oriented to ecosystems and to diverse biological interrelationships.

A common question about the Pintail Marsh is whether it accumulates toxics. Wilhelm, whose team has tested vertebrates, fish, and salamanders for organic chlorines and metals, reports that "there wasn't anything real far off. There was no detection of any of the organic chlorines (despite chlorination in the conventional front-end treatment system; see Figures 1, 2, and 3). The metals are kind of up and down, but nothing is out of whack."

The US Environmental Protection Agency (EPA) has funded further monitoring of Pintail Marsh as part of its continuing national program to collect in-depth data on the performance of natural treatment systems. Under the direction of environmental engineer Sherwood Reed, the EPA recently published the first national survey on the efficacy and costs of such systems*.

Some of the current EPA funding for Pintail is to document bird use of the marsh. Last spring Wilhelm and crew counted 96 species of birds in the wetland—as many as 58 in a single day. Among these were 10 threatened or endangered

* A copy of Reed's EPA survey is available for US$2.00 from Bio-Remediation Services Inc., 621 Old Santa Fe Trail #5, Santa Fe, New Mexico 87501 USA; for information, call 505-983-5549.

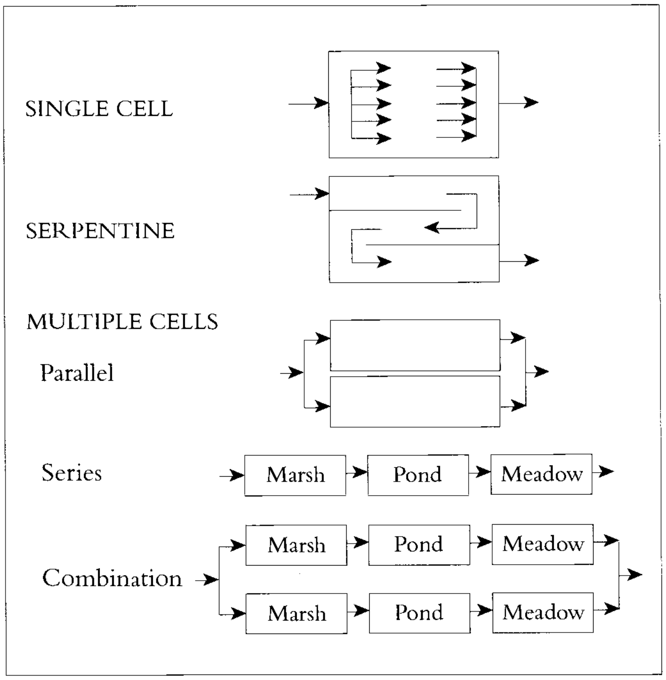

Figure 3. Five of the possible configurations for constructed wetlands.

species, including bald eagle and peregrine falcon. Wetlands are the most productive ecosystems on Earth (grains planted at Pintail Marsh yield 2,000 pounds per acre of seed for migrating birds), so it is hardly surprising that birds and other wildlife are attracted. One survey, in fact, counted an average of 76.4 ducks per hectare, an exceptionally high figure.

The vitality of the Pintail experiment has attracted lots of humans, too, from hunters to the National Audubon Society, which brings groups of schoolchildren to help plant the marsh. Interest has grown with plans to build a blind large enough to hold a classroom for 30 students.

"The environmental education part is one of the most enjoyable for me," Wilhelm says, although he admits that sometimes the lines between student and teacher can blur; to wit, the Case of the Precocious Engineer:

Safe from land-dwelling predators, many species of birds have come to nest on the small islands that dot Pintail Marsh. The islands were designed as suggested by a 10-year-old boy, who observed that V-shaped islands, if pointed into the prevailing wind, would both control erosion and create the backwater habitat favored by wildlife. The scheme worked so well that the engineers hired by nearby municipalities to design *their* wetlands followed the 10-year-old's lead.

"When you get into creating a wetlands," Wilhelm observes with a grin, "leave yourself some flexibility and some room, and then expect something out of the ordinary to happen."

***Kenny Ausubel** is the founder and chairman of Bio-Remediation Services (BRS) Inc., which specializes in the use of natural treatment systems for wastewater treatment. BRS co-sponsored the 1990 and 1991 Seeds of Change conferences in Santa Fe, New Mexico, which focused in-depth on the state of the art of bioremediation technologies.*

The Creation and Evolution of Jacques Marsh

John G. Wolan

The Pinetop-Lakeside Sanitary District in Arizona was attracted to the constructed wetland concept by the cold, calculating economic reality of the costs of wastewater treatment. We originally viewed the usefulness of our Jacques Marsh for recreation, wildlife habitat, and maintenance of species diversity as beneficial by-products of this constructed wetland's "real" function, which is to provide a substitute for expensive tertiary wastewater treatment equipment. The question that really interested us was this: What can a marsh do naturally that others in the industry currently are spending a lot of money on?

The answer to that question depends on the quality of the water introduced into the wetland and on the goals you have for your wetland. Wetlands are dynamic biological entities whose behavior can be guided and, to a greater or lesser extent, predicted. They are not mechanical devices in which an action leads always to the same reaction. Some marshes function as complete wastewater treatment systems, with raw sewage flowing in and a clear trout stream flowing out. At the other extreme are marshes that receive secondarily treated wastewater and still turn into algae farms. Most marshes fall within a predictable middle range and are an asset to a community.

Given the uncertainty of the outcome, one may legitimately ask why the Pinetop-Lakeside Sanitary District built a marsh. The answer is that we had few choices.

Pinetop-Lakeside grew rapidly during the 1960s and 1970s, a reality for which this rural community was not prepared. It soon became clear, however, that rocky clay soils and septic tanks on 100-foot-wide lots did not mix to good effect. A shallow aquifer became contaminated at depths of 60 to 120 feet and surface waters were mixed with a generous supply of effluents. A municipal sewer system obviously was demanded, but we still were faced with the problem of what to do with secondarily treated wastewater. Owing to water quality regulations, discharge into the Show Low Creek basin was prohibited and other alternatives, such as agricultural irrigation, industrial reuse, and overland flow, were not feasible. Ready or not, we were in the marsh business.

The Benefits of Constructed Wetlands

What are the benefits of marshlands? One answer is that there are certain plant species that can remove specific metals and other chemical compounds from wastewater. Also, the physical movement of water through vegetation can remove solids and biochemical oxygen demand (or BOD, in engineering shorthand), resulting in improved water clarity.

The major benefit, from our perspective, lies in a marsh's multiple uses in the areas of wastewater management, economics, recreation, and wildlife habitat. Constructed wetlands can form the core of a park or wildlife complex, adding biological and scenic diversity to an area, which can prove to be an economic asset to a community by attracting birdwatchers and other nature-loving tourists. It also can collect and store water for irrigating municipal parks, street plantings, and playgrounds, thus reducing the need to draw upon stocks of potable water. Aesthetically, a marsh with an overflow is much preferred to direct discharge of treated wastewater, no matter what its quality.

How Jacques Marsh Works

Jacques Marsh, then, is a reuse project. The primary wastewater treatment facility that feeds the marsh is a 2.5 MGD (million gallons per day) oxidation ditch, which produces an effluent of high quality. Water clarity is good—it is not unusual for the bottom of the marsh to be visible at depths of 3 to 4 feet—and we have had no problems with algal blooms or odors.

The marsh was constructed on a pinyon-juniper flat at 7,000 feet above sea level and consists of seven ponds with a combined surface area of 93 acres. Pond depths range from 1 to 5 feet and average 2.25 feet. A separate 35-acre storage basin can be filled during the winter rain-and-snow season to assist in maintaining water levels during the early summer dry season. Flows into the marsh average just under 1 MGD in the summer and about .6 MGD the rest of the year. Design capacity is 2.5 MGD; based on performance since the marsh began to receive water in 1980, we believe additional flows can be accommodated. Overflows from the marsh, if any, are designed to flow to a planned riparian development area.

Many constructed wetlands take advantage of topographic features such as dry lake basins or intermittent drainages to minimize earth-moving and dike-building, but Jacques Marsh had no history as a wetland. Site selection, therefore, began with a soil survey to locate tight clay soils of sufficient depth both to produce material for construction of berms and to seal the bottoms of the ponds. We also wanted a fairly level site. Because Jacques was one of the first marshes to be constructed in this area, a lot of time was spent on engineering and testing, and the system is very conservative.

Construction is pretty basic. Scrapers picked up material from the centers of the ponds-to-be and deposited it where berms were to be constructed. Surplus material was used to create islands—which serve as undisturbed nesting areas for waterfowl, act as barriers to reduce wave action, protect the berms, and add to the diversity of the marsh habitat—and to reinforce berms where erosion was expected.

Much of the vegetation in the marsh was planted from commercial nursery stock in the form of tuber root segments, which were individually pushed into bottom soils by hand. We since have transplanted clumps of established plants from Jacques to other marshes, and have found that these establish and spread much faster than do tuber segments or rootstocks.

A CONSTRUCTED MARSH MUST FIT THE ECOSYSTEM OF WHICH IT WILL BECOME A PART. REMEMBER, TOO, THAT A MARSH IS A LIVING SYSTEM AND, UNLIKE CONCRETE, IT – AND ITS OPERATOR'S GOALS – CAN CHANGE OVER TIME.

Control of water within the marsh complex is essential for efficient operation and maintenance. Jacques Marsh has a distribution system that allows operators to introduce water individually into five of the seven ponds, and there are water control structures between ponds that share a common berm. Thus the marsh can be operated as a flow-through system or as a series of individual ponds. This allows us to isolate an individual unit for maintenance or for special management purposes, such as growing forage crops for wildlife or livestock. Flexibility is the key to a successful marsh.

A constructed marsh must fit the ecosystem of which it will become a part. Remember, too, that a marsh is a living system and, unlike concrete, it – and its operator's goals – can change over time. Jacques Marsh, for example, was designed primarily for waterfowl nesting, and as such it has been very successful. But it also is grazed flat each winter by elk, and wild turkeys often visit during the summer months. Human visitation has increased dramatically, too, and management of the marsh is changing to reflect the diversity of uses. The marsh has become so popular with birdwatchers that tourism and environmental education are becoming increasingly important in making management decisions. As the community grows, the marsh may expand to become the focus of a park with a wildlife theme.

John G. Wolan *is District Engineer for the Pinetop-Lakeside Sanitary District in Arizona. His article is adapted from a paper he presented at an interdisciplinary riparian issues symposium sponsored by the Arizona Hydrological Society and the Soil and Water Conservation Society on November 15 and 16, 1991, in Tucson.*

Using Water Hyacinth (*Eichhornia crassipes* L.) to Treat Municipal Wastewater

Martin M. Karpiscak, Kennith E. Foster,
Susan B. Hopf, and Peter J. Warshall

Introduction

Interest has increased over the last several decades in treating municipal wastewater using aquatic plant systems as an ecologically and economically viable alternative to traditional treatment methods. The efficiency of floating aquatic plant species such as water hyacinth (*Eichhornia crassipes L.*), emergent plants such as cattail (*Typha* spp.), or submergent species such as pondweed (*Potamogeton* spp.) are being investigated.

Water hyacinths—large, floating, aquatic macrophytes—are believed to be native to South America and portions of Central America. They were first collected at the beginning of the nineteenth century by Alexander von Humboldt in Jamaica. By the end of that century the plant was widely grown in many European botanical gardens because of its beautiful lilac flowers, which resemble those of terrestrial hyacinth plants (Figure 1). Specimens also were sent around the world and eventually found their way into many waterways. They have since become a major weed throughout the warmer regions of the world and grow abundantly in North America, Africa, Portugal, southern and southeast Asia, Australia, and New Zealand (Gopal 1987).

In North America, water hyacinths probably were introduced somewhere in the Mississippi Delta in Louisiana in 1884 (Britton 1917, Penfound and Earle 1948). The plants now have spread throughout the southern coastal states and into California.

The water hyacinth, like other weeds, has flourished not only because of its ability to thrive under a wide spectrum of nutrient and climatic conditions, but also because of its ability to reproduce rapidly. Because dense stands of water hyacinth on waterways adversely affect transport of both people and agricultural and manufactured goods, and because they disrupt the indigenous ecosystem, a great deal of time and money has been expended worldwide in an effort to control the plant's growth and spread. Gopal (1987) provides a comprehensive discussion of this aquatic macrophyte, including its systematics, geographic distribution, morphology, reproductive biology, ecology, control, and use.

In the early 1970s, the potential for using water hyacinths as a mechanism for improving the quality of wastewater began to be explored by various wastewater managers and researchers. They seeded water hyacinths into existing ponds and measured the improvement in water quality. It was speculated that the improvement in water quality resulted solely from plant uptake of nutrients such as nitrogen and phosphorus. More recently, however, it has been shown that the total plant ecosystem, especially the bacteria associated with the plant's roots, may accomplish much more pollutant removal than plant uptake alone.

Figure 1. Water hyacinth in bloom.

Constructed or artificial wetland systems typically are simulated marshes comprising one or more plant species and operated for the purpose of wastewater treatment or other benefits to humans. The plants in these systems are adapted to fluctuating water and nutrient levels and generally are more tolerant of peak nutrient inflow than are packaged treatment systems. Water hyacinth plants provide shading that reduces algal growth, and they also decrease surface turbulence, transport oxygen to the root zone, and act as a biological filter, clarifier, and purifier.

Literature Review

Water hyacinth has been the species most studied because of its worldwide distribution, rapid growth, and extensive root system. Many studies have been on a laboratory scale, using only a few plants and lasting short periods of time. The studies typically used simulated nutrient solutions to determine improvements in water quality or nutrient removal as measured by one or more parameters, such as biological oxygen demand (BOD_5) or total suspended solids (TSS).

One of the most extensive series of studies was carried out by Wolverton and McDonald and their colleagues from NASA's National Space Technology Laboratories in Mississippi. Wolverton and McDonald (1975a) reported that BOD_5 and TSS levels were reduced by 77 and 75 percent, respectively. At Orange Grove, Mississippi, a summer study (July-September) conducted by Wolverton and McDonald (1975b,c) showed a large reduction in the concentration of TSS, total nitrogen, phosphorous, and fecal coliform in secondary effluent. A study conducted near Lucedale, Mississippi, between July and November by McDonald and Wolverton (1980) showed that water hyacinth plants were effective in decreasing BOD_5, TSS, nitrogen, and phosphorous levels.

At Williamson Creek near Austin, Texas, Dinges (1976) investigated the use of water hyacinths in several pilot studies. According to his report, the following wastewater parameters were reduced: TSS by 83.8-91 percent, BOD_5 by 79.4-87 percent, COD by 50-67 percent, total coliform by 92-97 percent, and fecal coliform by 97-99 percent. A pond with a surface area of 1.21 ha, a depth varying from 0.7 to 1.3 m, and operated with a detention time of 6.5 to 12 days was used in additional studies (Dinges 1979, 1981). The system was operated from October 1977 to December 1979 with an influent flow of 1325 m^3/day. Dinges found that BOD_5, TSS, and fecal coliform levels were reduced by 70, 77, and 94 percent, respectively.

Several authors recently have published volumes on the use of constructed wetlands in the treatment of wastewater, including Dinges (1982), Reed, Middlebrooks, and Crites (1988), and Hammer (1989). The U.S. Environmental Protection Agency (EPA) also has issued a preliminary design manual for constructed wetlands and aquatic systems for treating municipal wastewater (EPA 1988). However, data available at this time, especially from field studies, are limited, at times contradictory, and inadequate for optimizing process variables or achieving mandated standards under specified conditions (Hammer and Bastian 1989).

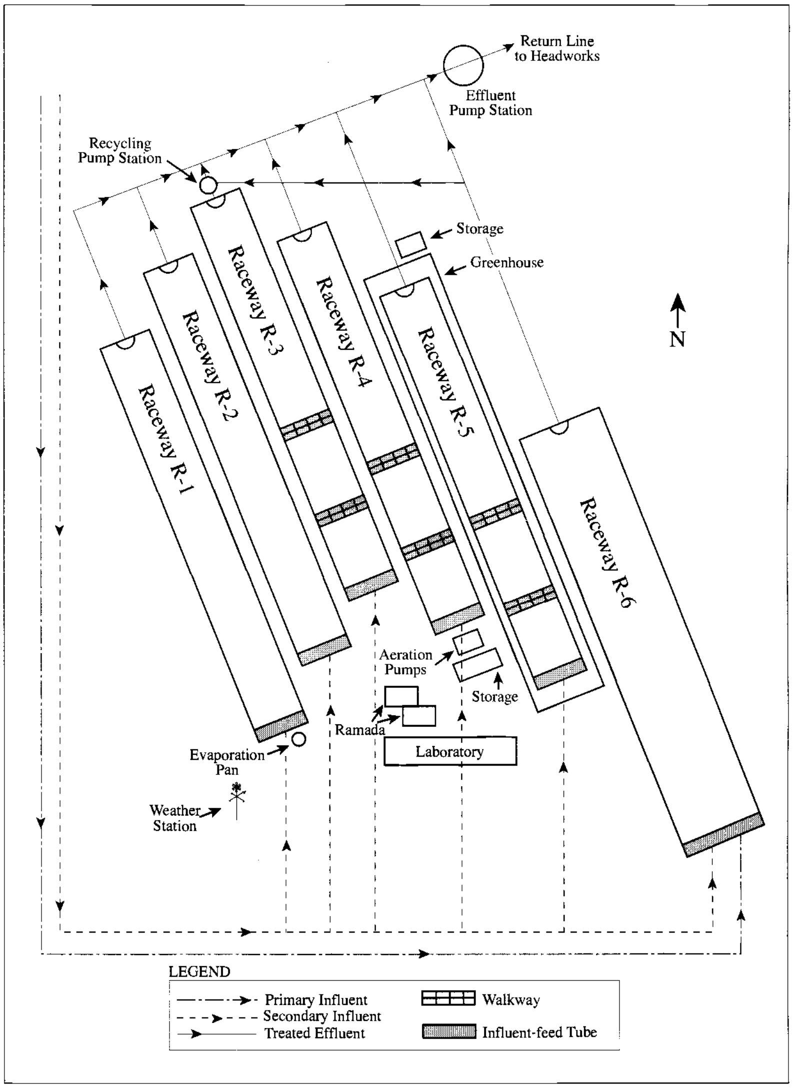

Figure 2. Water hyacinth pilot facility layout.

Description of the Facility

GENERAL BACKGROUND

The idea for the research/demonstration aquatic treatment system discussed in this article was conceived in 1983. Researchers at the University of Arizona's Office of Arid Lands Studies completed an assessment for the Pilot Facility in 1984 (Warshall, Jennings, and Cunningham 1984a, 1984b). Construction of the system was completed in late 1988 and the facility became fully operational in January 1989.

The main research interest at the facility is the evaluation of the ability of water hyacinth and other aquatic plant species to effectively and economically treat wastewater, specifically in the arid, sometimes very cold southwestern deserts of Arizona.

The Pilot Facility is adjacent to the existing Roger Road municipal wastewater treatment facility operated by the Pima County Wastewater Management Department, which treats water to secondary standards. The facility is close to the highly urbanized area of Greater Tucson. It is comprised of six raceways (ponds) and a house trailer that doubles as on-site headquarters and laboratory (Figure 2).

RACEWAYS/PONDS

All the raceways are oriented on a north-south axis and are lined with 30 mil hyperlon (heavy plastic sheeting). Five of the raceways each measure 61 m long, 8.2 m wide, and 1.4 m deep. The sixth raceway is larger at 64.6 m long, 11.9 m wide, and 2.6 m deep. During facility operation with hyacinths in place, the raceways have been filled to a depth of 0.9 m.

The influent pumped into the Pilot Facility typically has been treated secondary effluent diverted from the Roger Road facility just prior to chlorination and discharge into the Santa Cruz River. The average flow rate into each raceway has been 94.6-98.4 l/min. The secondary effluent enters the south end of a raceway and flows by gravity to the north end, where it drains into a collection well. All the treated wastewater is then returned to the headworks at the municipal facility. During the past year of operation (1990-91), primary effluent from the municipal facility also has been diverted to the Pilot Facility for treatment.

Various capabilities have been incorporated into the design of several of the ponds to evaluate optimum treatment methods. Raceways 1 and 2 are simple lined ponds, with wastewater entering, being treated, and leaving.

Raceways 3, 4, and 5, however, were designed with other capabilities. All three have the ability to "step-feed;" that is, to add influent water progressively down the length of the

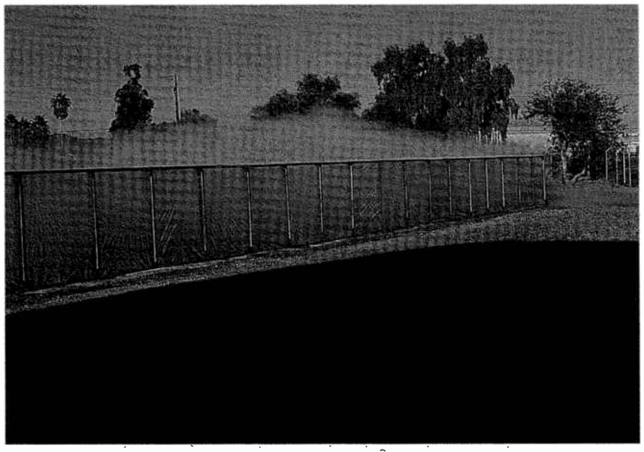

Figure 3. Fog protection system in operation.

runway. These raceways also contain aeration pipes along the south half of the bottom of each raceway so that dissolved oxygen levels can be increased. And because hyacinths are susceptible to frost damage at temperatures below 4.5°C, these three raceways also have been used in the examination of frost protection systems.

In Raceway 3, several Rainbird irrigation sprinklers are sited along each side of the pond. A portion of the secondary effluent wastewater treated in the raceway can be collected in a recycling well and pumped into the sprinkler system. Energy is released as the water turns to ice and the frozen water on the plant surface acts as a protective shield. The recycling well also provides a mechanism by which effluent treated in Raceway 6 can be recycled into Raceway 3 for additional treatment.

An MEE fog system can be used to provide frost protection in Raceway 4. The raceway was fenced using 10 cm x 10 cm wooden posts connected by top and bottom rails. A pipe with approximately 140 nozzles at 1-m intervals was fastened along the posts around the perimeter of the raceway. A pump pressurizes the system to 6,895 kPa and pumps water as fog at a rate of about 15.1 l/min. The small orifice of the nozzles requires that potable water be used in the system. Polyethylene sheeting is attached to the wooden railing using lath and wood screws during the winter to create a curtain that holds in the fog (Figure 3).

Raceway 5 has the most elaborate frost protection system of the three raceways. A Stuppy greenhouse was constructed over the raceway using double sheets of 6 mil Nutri Gro greenhouse film in the roof. The sidewalls are temperature controlled, so that they are automatically lowered in warm weather and raised during cold weather, providing a totally enclosed greenhouse for the plants.

ON-SITE HEADQUARTERS

The on-site headquarters was constructed from a residential single-wide mobile home (3.7 m x 18.9 m) salvaged from a local sanitary landfill. This structure was renovated to include two laboratories, a washroom, storage and meeting rooms, and an office/computer room.

The laboratory is used to analyze influent and effluent wastewater in order to determine improvement in water quality. Because the laboratory is on-site, samples can be analyzed immediately.

The computer room houses a Data Acquisition System that continuously monitors and records water-related and

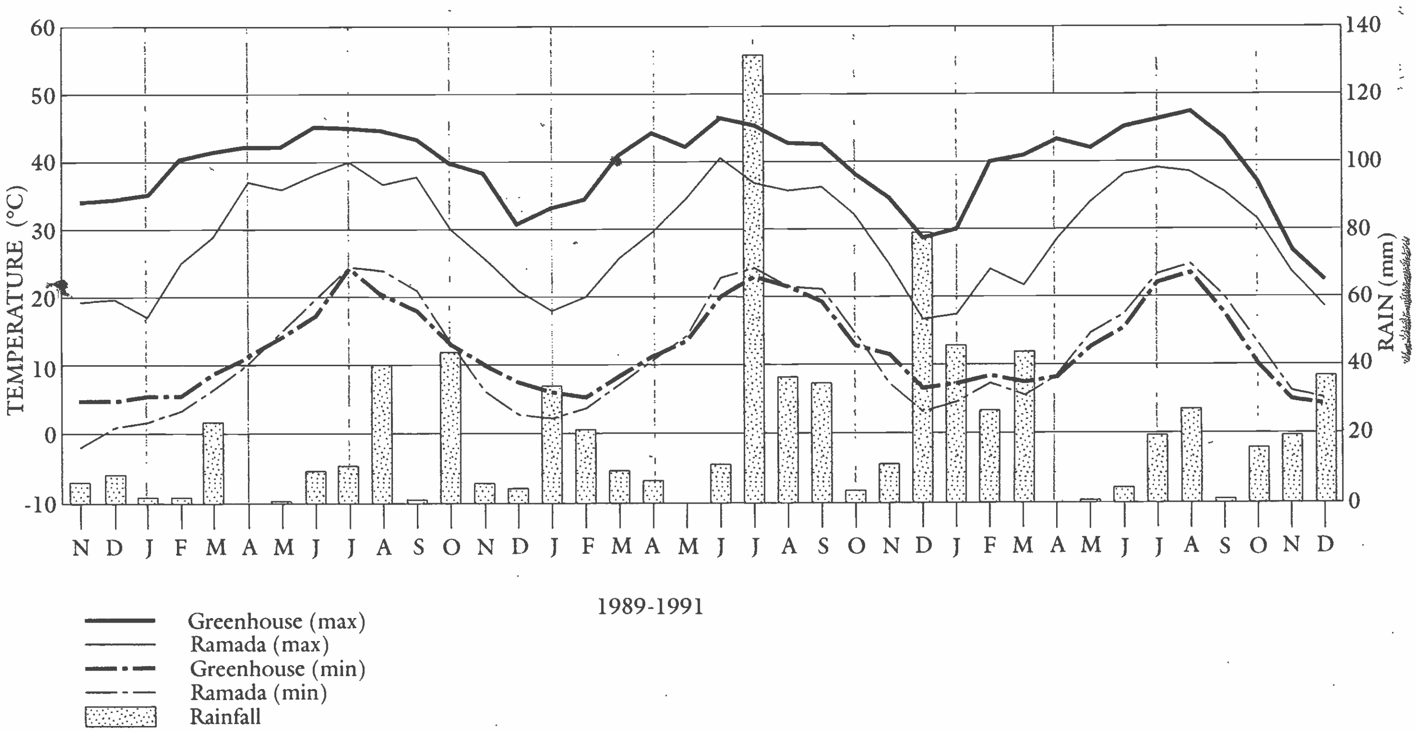

Figure 4. Average monthly temperature and total monthly rainfall, 1989-91.

meteorological data. Data such as flow rates into each raceway, water temperature, and total water volume exiting the facility are compiled.

Ramadas landscaped with arid-adapted plants provide additional work space and shading for an outdoor lunch area. The arid-adapted landscaping has become home to various indigenous animals.

CLIMATIC CONDITIONS

Average monthly temperatures, as recorded both in the greenhouse and at the on-site weather station, are presented in Figure 4. Although average monthly winter temperatures did not fall below freezing, freezing temperatures were recorded on several days during each winter the facility has been in operation. Rainfall, as would be expected, was very variable. July 1990 was an unusually wet month, with more than 130 mm of precipitation recorded.

OPERATIONAL PARAMETERS

As indicated above, secondary effluent has been flowing into Raceways 1 through 5 since the beginning of the project in 1989. Typically, the raceways have been operated in parallel and are designated as the Secondary Influent Treatment System (SITS). From September 1990 to June 1991, primary effluent was introduced into Raceway 6 and its effluent was recycled through Raceway 3, the two raceways being operated in series and designated as the Primary Influent Treatment System (PITS).

Total influent volume per SITS raceway was 142 m^3/day during 1990-91, slightly higher than the approximately 136 m^3/day recorded in 1989-90, since the average influent flow rate (98.4 +/- 11.4 l/min) during 1990-91 was slightly higher than in 1989-90. Detention time in each pond was about 2.7 days, with a hydraulic loading rate of 32.5 cm/day.

The average monthly SITS influent BOD_5 concentration was 20.1 mg/l during 1990-91, virtually the same as the 1989-90 average of 19.9 mg/l, yielding an organic (BOD_5) loading rate per raceway of 68.1 kg/(ha.day) in 1990-91.

Influent flow into PITS Raceway 6 during 1990-91 was approximately 94.6 +/- 11.4 l/min, or 136 m^3/day. Detention time in Raceway 6 was approximately 2.8 days. Because the total flow into Raceway 3 from Raceway 6 was recycled, the effective detention time for the two raceways in series was approximately 5.8 days. The organic loading rate based on an influent BOD_5 average of 100 mg/l was 163 kg/(ha.day).

As expected, the water temperature within the greenhouse (Raceway 5) was higher than in the other raceways on a month-to-month basis. In February 1991, it was almost 2-3°C higher. The annual monthly temperature range for the influent in each raceway varied from approximately 20°C in the winter months to approximately 30°C in the summer months. The effluent temperature range was 2-3° lower, varying from approximately 18°C to 28°C.

METHODOLOGY

The quality of the influent and effluent water from each raceway in both the SITS and PITS has been evaluated in the laboratory and in the field. Twenty-four-hour refrigerated composite samples and/or grab samples of wastewater from the wastewater treatment plant and from the effluent end of each of the individual raceways at the Pilot Facility were field-collected. On-site laboratory analyses for chemical and biological parameters were conducted to determine the efficiency of the water hyacinth treatment systems. Improvements in water quality were measured as the percent reduction of each species of interest between the influent entering and effluent leaving each raceway (Table 1).

Dissolved oxygen content, water temperature, and flow rates were monitored in the field and plant samples were collected almost monthly from each raceway between September 1988 and July 1990 to determine plant health.

The operating parameters of the facility have been varied to evaluate changes or trends in water quality treatment. The frost protection systems were employed only during the first two full winters of operation. To ascertain differences in treatment between younger and older, more established plants, 90 percent of Raceway 2 plants were harvested in September 1989 (Figure 5). Monthly harvests of 10-20 percent were carried out between April and October, 1990 and 1991. Influent flow rate into designated raceways in the SITS has ranged from no flow to a maximum of 113.6 l/min, altering the detention time.

Table 1. Monthly percentage reduction from secondary influent to effluent of chemical species in water samples, 1989-91.

Month	pH	BOD	TSS	NO_3-N	NO_2-N	NH_3-N
Mar 89	5.7	67.6	(100)[a]	—	—	—
Apr	6.7	65.3	(100)	—	—	—
May	6.9	73.4	(100)	—	—	—
Jun	5.7	74.3	(100)	—	—	—
Jul	3.9	53.2	(100)	—	—	—
Aug	3.7	72.3	(100)	—	—	—
Sep	4.9	79.7	(100)	—	—	—
Oct	4.1	77.8	(100)	—	—	—
Nov	3.1	61.5	(100)	—	—	—
Dec	3.1	54.6	(100)	(100)	(100)	—
Jan 90	0.8	70.0	(100)	(100)	(100)	—
Feb	0.0	77.4	(100)	64.4	69.0	—
Mar	1.5	64.8	(100)	82.8	90.5	+3.7
Apr	3.4	59.8	(100)	84.4	(100)	28.1
May	3.1	65.8	(100)	95.3	(100)	18.1
Jun	3.7	57.6	(100)	94.1	91.4	17.4
Jul	3.7	66.0	(100)	93.2	94.0	+10.4
Aug	3.3	51.7	(100)	88.2	90.7	39.0
Sep	3.0	55.6	(100)	79.2	84.2	43.3
Oct	7.1	70.2	(100)	69.2	86.2	36.3
Nov	4.1	39.2	(100)	94.7	(100)	10.3
Dec	2.1	56.2	(100)	92.1	96.1	14.4
Jan 91	2.1	69.8	(100)	92.5	91.5	+5.0
Feb	0.7	74.3	(100)	60.2	65.7	10.4
Mar	1.2	72.1	(100)	(100)	97.1	5.6
Apr	3.3	65.0	(100)	91.0	(100)	3.4
May	5.1	54.5	(100)	(100)	(100)	8.4
Jun	3.6	71.6	(100)	94.2	93.3	11.8

Figure 5. Water hyacinth plants being harvested mechanically; they can, of course, also be harvested by hand.

Results and Discussion

This section discusses some of the research findings to date, particularly those that are critical in evaluating the potential use of such systems in Pima County, Arizona. A summary of the monthly average percent reductions in the water quality parameters of interest is presented in Table 1.

GENERAL

In defining water quality improvement, two of the most important parameters are BOD_5 and TSS. The EPA tertiary standard requires that the BOD_5 and TSS concentration in effluent from a treatment system be less than 10 mg/l. The Pilot Facility has met this standard in the SITS for every month of its operation except March 1990 (Figure 6). In addition, the secondary standard for BOD_5 (30 mg/l) was achieved in the PITS for most of the 10-month period it was in operation. The secondary standard for TSS (30 mg/l) in the PITS was achieved every month.

Because reduction in total nitrogen levels in wastewater also is of paramount importance, the following discussion examines these parameters in the SITS.

BIOLOGICAL OXYGEN DEMAND

The monthly average percent reduction in BOD_5 at the Pilot Facility SITS during 1990-91 was 62.1 +/- 10.2 percent, compared to 65.6 +/- 7.9 percent during 1989-90. The largest reduction occurred in February of both periods (77.3 percent and 73.9 percent, respectively). Monthly average BOD_5 concentration for both influent and effluent is presented in Figure 6.

The monthly average effluent concentration was 7.1 +/- 2.1 mg/1 (1990-91), slightly higher than the 1989-90 average of 6.7 +/- 1.6 mg/1. The slightly higher 1990-91 average may have resulted from a shorter detention time, since the influent flow rate was slightly higher.

The seasonal variation in BOD_5 concentration in both the secondary influent and effluent during 1990-91 was similar to that during 1989-90, with higher concentrations occurring during the winter months (January-March) and lower concentrations during the summer months (June-August).

TOTAL SUSPENDED SOLIDS

Although there were occasional instances of detectable TSS in SITS effluent, in general no detectable TSS (<5 mg/1) was found on a monthly average basis. The tertiary TSS

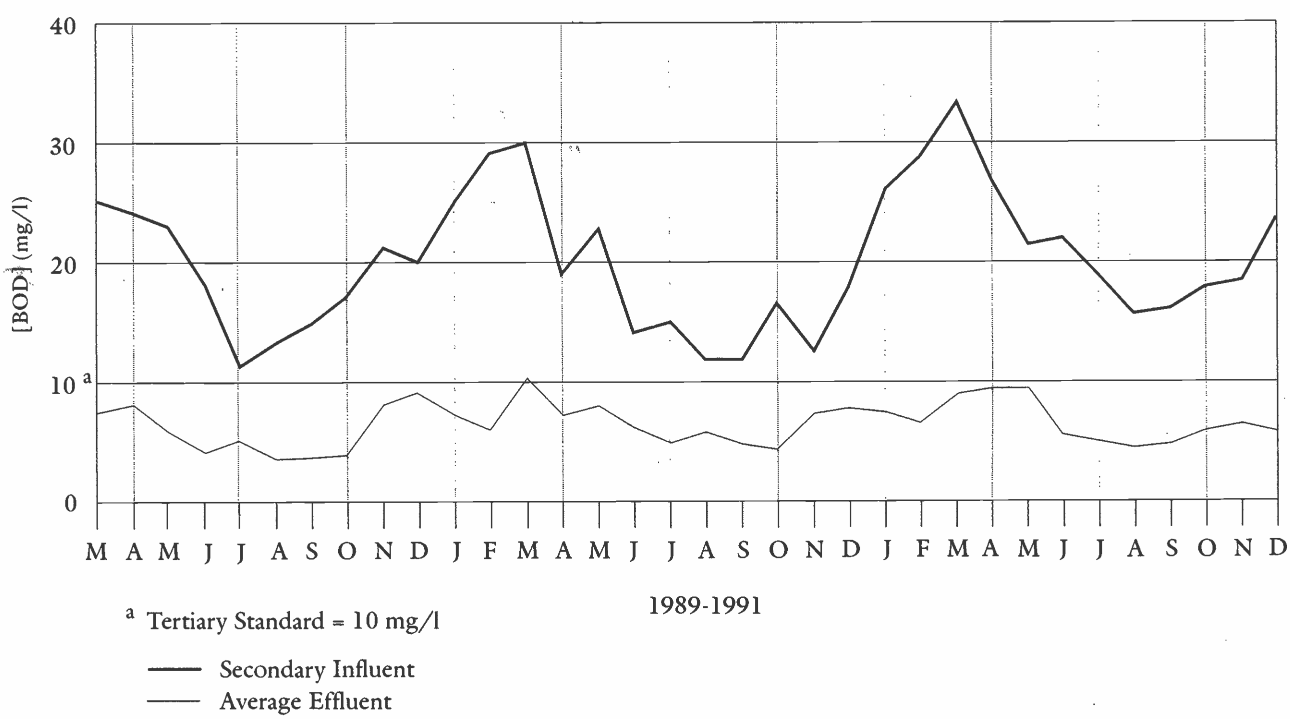

Figure 6. Monthly average biological oxygen demand (BOD_5) concentration in SITS influent vs. effluent, 1989-91.

standard (10 mg/1) was met during every month since analysis was started in March 1989.

NITROGEN SPECIES

SITS nitrate-nitrogen (NO_3-N) and nitrite-nitrogen (NO_2-N) were reduced on a monthly average of 87.9 +/- 11.8 percent and 93.0 +/- 9.6 percent, respectively, during 1990-91. Ammonia-nitrogen (NH_3-N) was reduced 14.0 +/- 16.3 percent. Overall, the monthly average percent reduction in total nitrogen was 39.7 +/- 15.0 percent, with the greatest reduction occurring in August and September. Total N values were higher during the winter months and decreased significantly with the advent of warmer temperatures (March 1991) in both the influent and the effluent.

FROST PROTECTION

Water hyacinth plants responded to temperatures below 5°C with brown and necrotic plant tissue, especially in raceways that received no frost protection. In protected raceways, some browning and necrosis were observed.

The efficiency of the SITS frost protection systems was mathematically analyzed in terms of the reduction in BOD_5 level between the influent and effluent in each raceway. A coefficient of BOD_5 reduction (K) was calculated for each raceway/protection system during the winter seasons when the system was in use.

Analysis indicates that the greenhouse system (Raceway 5) performed best (BOD_5 reduced 71.5 percent). The K value of each of the other raceways, with and without a frost protection device, was essentially the same, indicating that a frost protection system is not essential to plant survival and/or improvement in water quality. The amount of improvement in BOD_5 levels indicates that during the winter, unprotected young plants (Raceway 2) were less efficient in reducing BOD_5 (63.9 percent) than were the older unprotected plants (Raceway 1; 68.2 percent) or the older protected plants (Raceways 3, 4, and 5).

A frost protection system does not appear to be essential to water quality improvement, but plants should be mature and well-established to obtain maximum improvement in water quality. If a frost protection system is deemed necessary, a low-cost sprinkler system, which can recycle effluent water, is nearly as effective as a capital-intensive and high maintenance-cost greenhouse.

HARVESTING

Both BOD_5 and TSS levels increased considerably in Raceway 2 after the harvest of 90 percent of the plants in September 1989. The average effluent BOD_5 concentration for Raceway 2 was 8.3 mg/l, compared to a pre-harvest level of about 2.6 mg/l and an average of 3.0 mg/l for the other raceways. TSS was detectable in the Raceway 2 effluent for almost two weeks after the harvest, whereas it was not detectable in the effluent from the unharvested raceways. This most likely was the result of disturbing the pond's sediment during the harvest.

The smaller weekly (10-20 percent) harvest of plants in Raceway 2 did not appear to affect wastewater treatment.

THE USE OF WATER HYACINTH OR OTHER PLANTS IN CONSTRUCTED WETLANDS SHOULD BE CONSIDERED A VIABLE ALTERNATIVE TO MORE TRADITIONAL WASTEWATER TREATMENT, ALTHOUGH THE INTRODUCTION OF AN AGGRESSIVE WEED SUCH AS WATER HYACINTH INTO AREAS WHERE IT COULD BECOME A MAJOR PEST SHOULD BE AVOIDED.

BOD_5 and TSS effluent levels were the same when compared to levels in the other raceways.

DETENTION TIME/FLOW RATE

Small variations in influent flow rate and subsequent detention time did not significantly affect reduction of BOD_5. During one three-week study, however, three flow rates were studied: 113.6, 53.0, and 15.1 l/min, with average percent reduction in BOD_5 measured at 77.4, 81.0, and 82.3 percent, respectively.

SUMMARY

Aquatic plant systems or constructed wetlands using water hyacinths and/or other species are capable of treating domestic wastewater in the Greater Tucson region, while at the same time providing wildlife habitat commonly associated with naturally occurring wetlands or effluent-dependent riparian communities. When compared with other water hyacinth treatment facilities, the Pima County facility continues over the long term successfully to treat secondary influent to attain the tertiary standard of 10 mg/1 in the effluent for BOD_5 and TSS. The average monthly percent reduction in BOD_5 levels since the facility became operational is 64.8 +/- 9.0 percent. The Pilot Facility also has been very successful in treating primary influent for a period of 10 months. The average monthly percent reduction in BOD_5 and TSS levels has been 63.5 +/- 10.5 percent and 84.3 +/- 10.4 percent, respectively.

Whether protected against freezing winter temperatures or left unprotected, water hyacinths were able to survive several winters in the Tucson area with major damage limited to the upper canopy. The plants recovered quickly with the advent of warmer temperatures in spring.

Research at the Pilot Facility has shown that water hyacinth plants can successfully treat both primary and secondary effluent in the Tucson area. Additional research, however, is required to adequately evaluate the use of wetlands systems for achieving the changing and increasingly stringent standards mandated by US federal and state regulations. We now are expanding our studies to include other species, such as duckweed (*Lemna* spp.), and the concept of using multiple plant species systems to achieve the goals of both wastewater treatment and enhancement of wetlands habitat.

The use of water hyacinth or other plants in constructed wetlands should be considered a viable alternative to more traditional approaches to wastewater treatment, although the introduction of an aggressive weed such as water hyacinth into areas where it could become a major pest should be avoided. The most obvious solution to this problem would be to identify local species that could provide reasonable levels of treatment while adding to the extent of wetlands habitat. In arid areas of the world, the use of aquatic plants to improve the quality of wastewater could provide additional water that would be suitable as irrigation water and/or industrial processing water. The plants also can be harvested and used as a soil conditioner.

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References

Britton, N.L. 1917. *Piaropus azureus. Addisonia* 2:67-68.

Dinges, R. 1982. *Natural systems for water pollution control.* New York: Van Nostrand Reinhold, Co. pp.71-110.

—. 1981. *The employment of floating macrophytes for water depuration and biomass production.* Paper delivered at conference on Phyto-depuration and Employment of the Biomasses Produced, held at Instituto di Ecologia, University of Parma, Italy. Austin: Texas Department of Health, Division Wastewater Technology and Surveillance.

—. 1976. A proposed integrated biological wastewater treatment system. In J. Tourbier and R. Pierson (eds.), *Biological control of water pollution.* Philadelphia: University of Pennsylvania, University Press.

—. 1979. Development of hyacinth wastewater treatment systems in Texas. In R.K. Bastian and S.C. Reed (eds.), *Aquaculture systems for wastewater treatment: Seminar proceedings and engineering assessment.* Washington, DC: EPA, Office Water Program Operations.

EPA (US Environmental Protection Agency). 1988. *Constructed wetlands and aquatic plant systems for municipal wastewater treatment.* EPA/625/1-88/022. Cincinnati: Center for Environmental Research Information.

Gopal, B. 1987. *Water hyacinth.* New York: Elsevier Science Publishers Company.

Hammer, D.A. (ed.). 1989. *Constructed wetlands for wastewater treatment: Municipal, industrial and agricultural.* Chelsea: Lewis Publishers, Inc.

Hammer, D.A. and R.K. Bastian. 1989. Wetlands ecosystems: Natural water purifiers? In D.A. Hammer (ed.), *Constructed wetlands for wastewater treatment: Municipal, industrial and agricultural.* Chelsea: Lewis Publishers, Inc.

McDonald, R.C. and B.C. Wolverton. 1980. Comparative study of wastewater lagoon with and without water hyacinth. *Economic Botany 34:101-10.*

Penfound, W.T. and T.T. Earle. 1948. The biology of water hyacinth. *Ecological Monographs* 18:447-72.

Reed, S.C., E. J. Middlebrooks, and R.W. Crites. 1988. *Natural systems for waste management and treatment.* New York: McGraw-Hill Co.

Warshall, P., M. Jennings, and B. Cunningham. 1984a. Pima County water hyacinth pilot treatment plant: A preliminary assessment for Pima County Wastewater Management Department: Task 1 report (August), Pima County Contract 01-03-U-104978-0384. On file Office of Arid Lands Studies, College of Agriculture, University of Arizona, Tucson, Arizona.

—. 1984b. Pima County water hyacinth pilot treatment plant: A preliminary assessment for Pima County Wastewater Management Department: Task 1 report (June), Pima County Contract 01-03-U-104978-0384. On file Office of Arid Lands Studies, College of Agriculture, University of Arizona, Tucson, Arizona.

Wolverton, B.C. and R.C. McDonald. 1975a. Water hyacinths and alligator weed for removal of lead and mercury from polluted waters. *NASA Technical Memorandum* X-72723. National Space Technology Laboratory, Bay St. Louis, Mississippi.

—. 1975b. Water hyacinths for upgrading sewage lagoons to meet advanced wastewater treatment standards. Part I, *NASA Technical Memorandum* X-72729, National Space Technology Laboratory, Bay St. Louis, Mississippi.

—. 1975c. Water hyacinths for upgrading sewage lagoons to meet advanced wastewater treatment standards. Part II, *NASA Technical Memorandum* X-72730. National Space Technology Laboratory, Bay St. Louis, Mississippi.

Martin M. Karpiscak *is a Research Scientist with The University of Arizona's Office of Arid Lands Studies (OALS).* ***Kennith E. Foster*** *is Director of OALS.* ***Susan B. Hopf*** *is a Research Specialist with OALS.* ***Peter J. Warshall*** *is an Adjunct Research Scientist with OALS.*

Development of a Conceptual Model for Floodplain Restoration in a Desert Riparian System

Holly E. Richter

Among the many natural systems impacted by humankind through history, perhaps none have been more drastically altered than floodplain ecosystems. Much of the impact is attributable directly to changes in the hydrologic regimes supporting these sensitive environments. This problem is particularly acute in arid environments, where human cultures the world over have become increasingly reliant upon limited water supplies for their survival. Rapidly growing populations in desert areas have increased the demand on these natural systems for water supplies through groundwater extraction, surface water diversion, and reservoir construction. Other uses of these areas over the past century, including off-road vehicle recreation, overgrazing, and construction activities, also have dramatically reduced natural floodplain environments and their associated riparian plant communities.

Because so few of these vital areas remain today, land managers are attempting to improve the condition of disturbed riparian areas by enabling them to return to earlier, more natural conditions. Unfortunately, many restoration projects address only manipulations of the vegetative patterns found in disturbed ecosystems, rather than focusing on the natural processes that create them. Floodplain restoration may be impossible, for example, without a thorough understanding of the complex hydrologic processes that sustain floodplain communities. Efforts to manage or restore the vegetation in riparian communities without fully appreciating these intricate relationships most likely will fail.

Riparian restorationists are challenged by many complex questions. Why have certain native species declined or disappeared within a floodplain? Why have exotic species invaded? Why is the overall vigor of the riparian community poor? This article draws upon the disciplines of community ecology, hydrology, and land management planning as a framework for answering similar questions in a specific case study at the Hassayampa River Preserve in the Sonoran Desert near Wickenburg, Arizona.

First, a characterization of the existing floodplain community as a mosaic of "patch types" is discussed. Next, determination of the important ecological processes, including the hydrological regimes, acting upon those patches is described. Finally, a conceptual ecological model that can be used to plan management activities for a specific site is developed.

Plant/Water Relationships

The availability of water plays a primary role in determining the composition, structure, and density of wetland and riparian plant communities and patch types. Johnson and Lowe (1985) have described the moisture gradient associated with the aquatic-to-upland continuum as a major factor controlling the biologic diversity and structural complexity of riparian ecosystems in the southwestern United States. They refer to a "transriparian continuum" that extends from the water in a stream or lake into the surrounding upland. In moving along this continuum one traverses several aquatic and terrestrial habitat types, from deep water through semiaquatic, riparian, semiriparian, and, finally, upland ecosystems, in that order. Soil moisture follows a continuum from complete saturation on the bottom of a lake or stream to little measurable moisture at the top of an adjacent rocky hill. Even within a single aquatic or terrestrial habitat type, however, much variability exists.

The structure and spatial patterns of riparian and wetland plant communities are manifested largely by interactions among available soil moisture, the flood or inundation regime, and the topography of the site, reflecting species-specific differences in water tolerance, preference, and flood relationships (Ward 1989; Gill 1973; Decamps 1984; Nilsson 1984; Pautou and Decamps 1985; Stanford and Ward 1986). The flora responds to differences in the timing of changing levels of groundwater or standing surface water, to direct actions of the flood regime (including scour and submergence), and to associated changes in soil characteristics (texture, pH, oxygen availability), microbial activities, and nutrient dynamics. A fundamentally important aspect of understanding ecosystem dynamics in floodplain systems is to understand the natural processes that influence the patterns of a plant community or landscape. Pickett and White (1985) have defined "patches" as discrete (sub-) communities embedded in an area of dissimilar community structure and composition. Definition or classification of "patch-types" can be useful in studying riparian communities, where considerable variability in micro-topography, water availability, and intensities of flood disturbance typically create a mosaic of vegetative patches. These patches often differ quite visibly in composition, structure, or density of vegetation. For the purpose of understanding patch type patterns within a riparian community, biotic diversity among patch types may be defined by: (1) differences in species compositions, particularly those characterized by different dominant species; (2) differences in structural or age classes, representing distinct seral stages of similar species associations, and (3) differences in species densities.

Table 1 presents a patch type classification scheme created for the cottonwood-willow riparian forest (*Populus fremontii/Salix gooddingii*) at The Nature Conservancy's Hassayampa River Preserve in Arizona. Of the abiotic characteristics, depth to water was the most statistically significant in defining the patches (Richter 1991).

Applications of Conceptual Models for Management of Riparian Areas

Identification of patch types within the overall community may yield "signatures" of the ecological processes

Table 1. Abiotic characteristics of riparian patch types at Hassayampa River Preserve.

Patch Type	Mean Depth to Water Table	Mean Height Above Stream Bed	Mean[1] Distance From Stream
Streamside Herbaceous	.45m	.62m	3.7m
Seepwillow Terrace	.79m	1.35m	9.39m
Cottonwood/Willow Saplings	.71m	.89m	9.5m
Cottonwood/Willow Pole Stand	1.31m	1.26m	21.60m
Mature Cottonwood/ Willow	2.20m	2.44m	48.10m
Mesquite Bosque	2.72m	2.87m	72.00m
Overflow Channel	1.18m	1.37m	36.40m
Burrobrush Terrace	2.18m	2.26m	55.60m

[1] Distance measures from stream thalweg

occurring across the floodplain. By understanding the physical and biotic variability among patches of a community, the structure and function of the community as a whole can be more easily understood. This concept is described well in an introduction to a text on wetland modelling (Mitsch et al. 1988):

> *It is our firm belief that to manage these systems properly and to optimize their roles in the landscape, we must understand quantitatively how these systems work and what to expect when we disturb or change them. We must further understand how by changing one part of a wetland we affect the rest of the wetland and downstream systems as well. We believe that ecological modelling, which includes both conceptual and simulation modelling, offers a tool to describe, quantify, and predict the behavior of these systems.*

Silvert (1989) adds:

> *The utility of modelling in the management of exploited populations and of ecosystems in general has long been recognized, but its utilization has lagged far behind. The reasons for this are not clear, but at least one reason seems to be the inaccessibility of modelling to managers and decision makers, who may not be familiar with computer models and may consequently be reluctant to rely on procedures which seem arcane and obscure to them.*

Conceptual models, unlike simulation or quantitative models, may be quite simple yet still provide valuable insights into the consequences of land management activities.

Many scales of pattern and process may be reflected by models, including broad conceptual models that may not apply to specific communities, such as those of Grime (1979), Huston (1979), and Tilman (1982), or to site-specific models with lower levels of generality or transferability (Day et al. 1988). Site-specific models probably have the most to offer land mangers in making site-specific land management decisions.

The applied uses of conceptual ecological models may be as varied as the management goals and information needs that inspired creation of the model. Understanding the ecological processes and functions of a community is essential for managing existing protected natural areas, for restoring degraded habitats or altered systems, and for prioritizing acquisition of additional natural areas. Two specific motivations for developing a conceptual model as a land management tool are:

(1) *Developing predictive capabilities for the future.* If the hydrologic processes and vegetation dynamics of a natural system cannot be described in the form of a conceptual model, the effects of future human disturbances cannot be anticipated or demonstrated. Conversely, it also would be difficult to assess the potential for restoration of natural processes and the resultant patterns of biodiversity of a disturbed system without an ecological model. Models also may identify ways to promote natural recovery of ecosystems, eliminating the need for more active approaches to restoration, such as tree planting.

(2) *Understanding previous human influences on the site.* Sites that are considered "natural areas" or pristine sites may actually be areas that have been affected hydrologically, geomorphologically, and/or ecologically by human disturbances that occurred a long time ago or far away from the site. Developing conceptual models that describe the current structure and processes of a system can assist in identifying subtle changes, transitions, or recovery patterns that occur over long periods of time or that may not be readily apparent.

Causes and effects may be separated not only by time but also by space. For example, the effects of dam construction may have ramifications on a river system far away from the construction site for a long period after the structure has been built. Several hundred years of adjustment may be required over distances of hundreds of miles, and a stream segment of concern may thus be located a long distance from the cause of disturbance (Hammoad 1972; Heede 1986). Management or restoration efforts that ignore these effects are likely to fail.

Developing a Conceptual Model for the Hassayampa River Preserve

A conceptual model for the Hassayampa River Preserve was developed as shown in Figure 1. The goals of this model were: (1) to understand how previous land uses may have affected the riparian community, (2) to describe the dynamics of the ecosystem and the role played by flooding in ecological "maintenance" or perpetuation of the community, and (3) to predict how human influences in the future, which may change the hydrological regime, will affect the riparian community.

This model initially was developed from mapping patch types within the riparian forest in the field and from topographic surveys of the "height above stream" and "depth to water table" within each patch. These basic measurements quickly unveiled new insights into the relationships between patch types and hydrologic influences in the community. The model depicted in Figure 1 resulted from interpretation of the influences that depth to water table and flood intensity have on these patch types and of the geomorphic processes that "move" the community from one patch type to another.

Data analysis (Richter 1991) revealed that depth to water table was closely correlated with species recruitment and composition in the riparian forest, and was particularly influential in setting the upper limits of a plant species' (or patch type's) position on the floodplain. Conversely, ability to withstand flood scour may define the lower topographical limits of a plant species or patch type in the floodplain. Monitoring over time will help to validate and refine this model as additional information is collected. Data from flood events that occur only infrequently will be especially helpful in understanding long-term processes.

To date, several important management and restoration concepts have been developed from this conceptual model. First, a deeper understanding of the impacts of previous land uses and the potential for natural recovery emerged.

When the Hassayampa River Preserve was first established, the elimination of artificial processes, including off-road vehicle use and livestock overgrazing, led to "restoration" of the site in some areas through natural recovery. Substantial recruitment of young cottonwood or willow had not occurred at the site for many years prior to the establishment of the preserve. The forest was dominated by mature and decadent trees even though a natural flooding regime had remained intact. The impacts of off-road vehicles and overgrazing along the fragile streambanks not only had damaged seedlings directly, but also had prohibited the establishment of seepwillow terraces (Figure 2), which functioned as important nursery sites for cottonwood and willow seedlings and saplings. Few seepwillow (*Baccarhis*

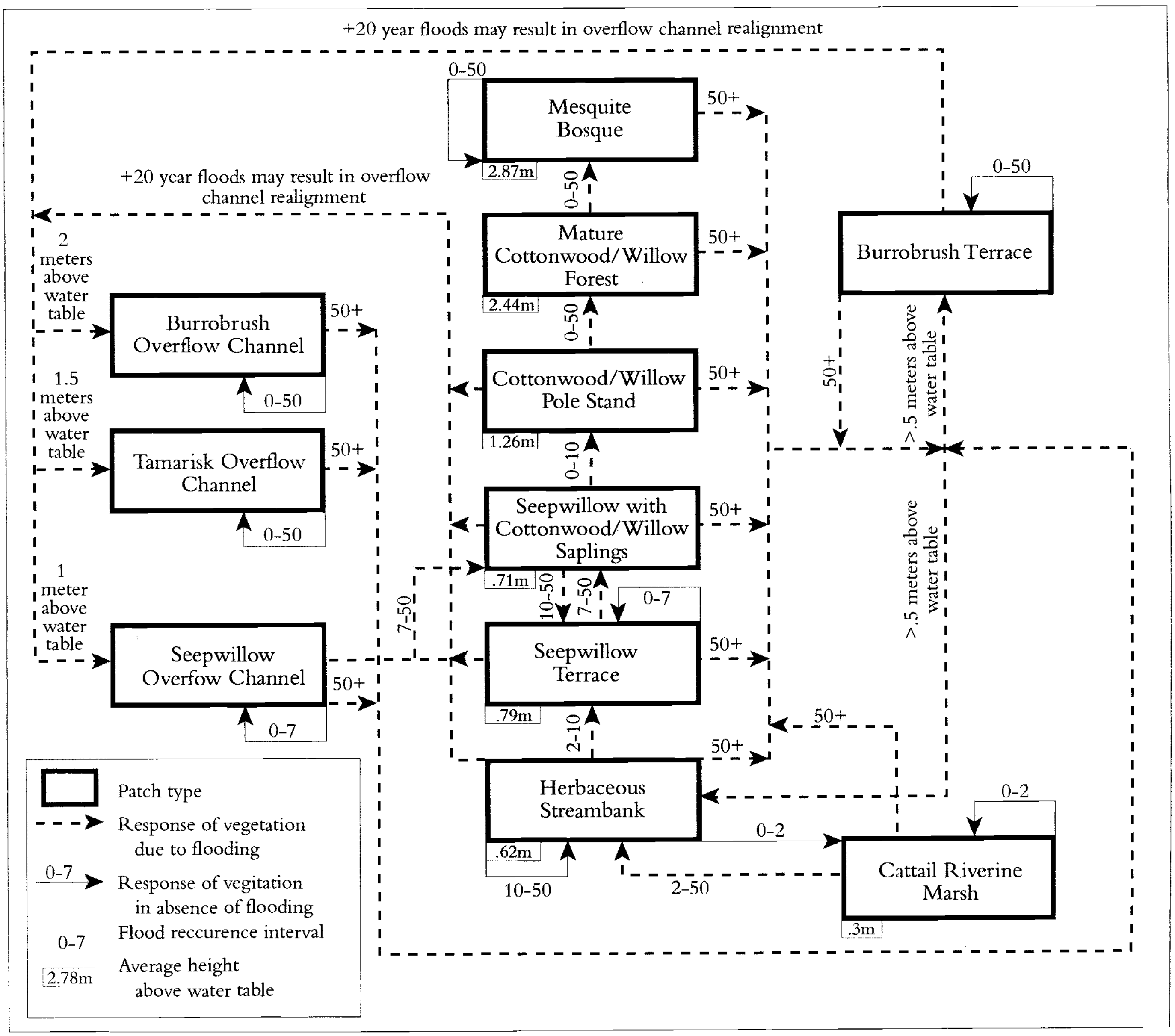


Figure 1. Ecosystem processes and vegetational dynamics of the Hassayampa River Preserve.

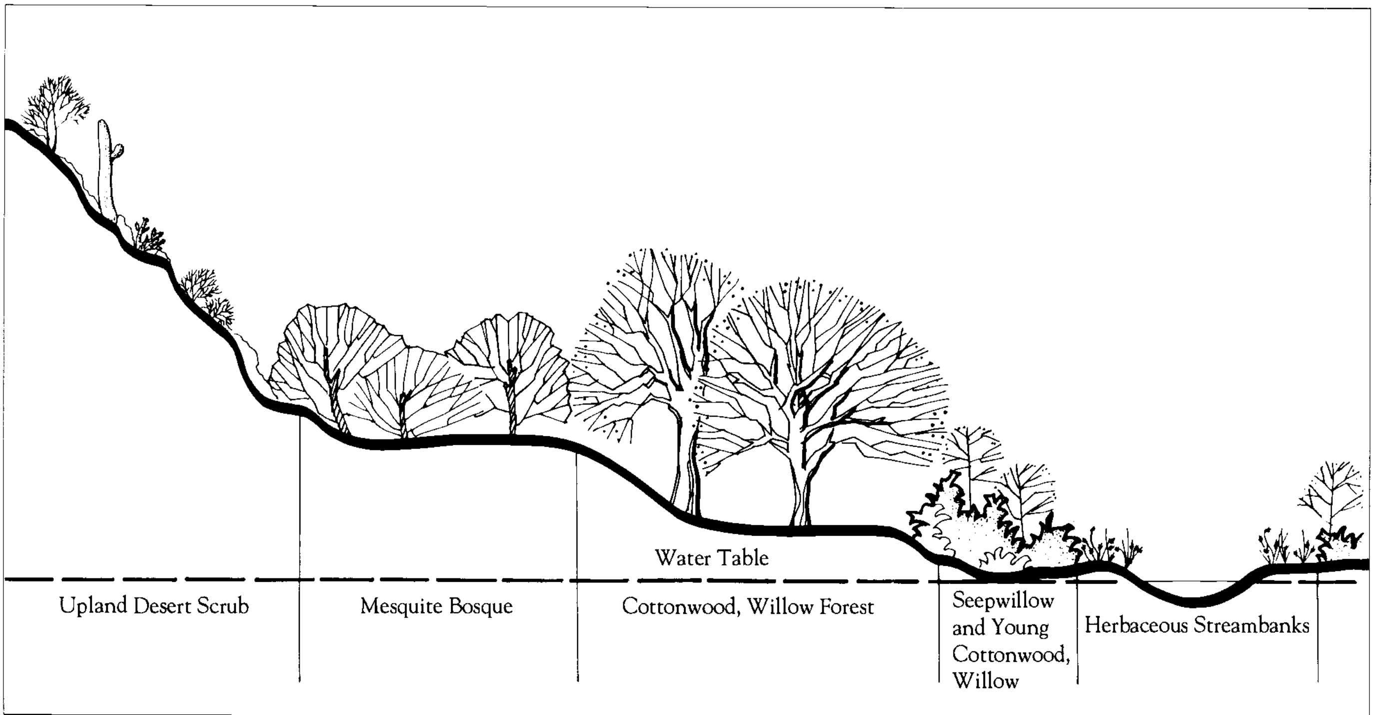


Figure 2. Typical floodplain cross-section, showing relationship of patch types at the Hassayampa River Preserve.

glutinosa) plants remained at the site, resulting in more vulnerability of fragile seedlings to scouring stream flows. Seepwillow terraces began to establish along the streambanks and cottonwood and willow seedlings began to appear within the first growing season following removal of artificial disturbances.

A second patch type—cattail riverine marshes along the river channel—emerged after artificial disturbances were removed. Cattails (*Typha domingensis*) are very vulnerable to damage from continual artificial disturbances. Interestingly, these marshes also appear to be intolerant even of relatively small magnitudes of natural disturbance from flooding (more than a two-year event). Natural flood regimes differ from the aforementioned artificial disturbances, however, in that they are episodic and not continual, which allows adequate time for cattail recovery between episodes.

This analysis also resulted in improved predictive capabilities. If a reservoir were to be constructed upstream of the preserve, for example, it most likely would result in elimination of scouring flood flows and of the nutrient-laden sediment they deliver to the preserve. According to the model, most of the patch types present at the preserve require flooding for their establishment. The herbaceous streambanks apparently would not develop into a seepwillow terrace without small (two- to ten-year) floods, which deposit fine sediments along the banks and allow the terraces to build. Subsequently, flood magnitudes equal to at least the seven-year event appear necessary to remove a sufficient percentage of the competing herbaceous cover within seepwillow terraces to allow cottonwood and willow seedlings to become established on these sites (Stromberg et al. 1991).

The progression of other patch types from "herbaceous streamside community" to "mesquite bosque" may be driven by many potential combinations of flooding scenarios. What impact might an upstream reservoir have on this riparian community? According to the model, without a natural flood regime any pre-existing patches of seepwillow with cottonwood and willow saplings most likely would develop into cottonwood/willow pole stands, then into mature cottonwood/willow forest, and eventually give way to mesquite. Unfortunately, without the natural flood disturbances that enable different patch types to regenerate and to start the cycle over again, the forest most likely would become an extensive mesquite bosque without cottonwood or willow. Cattail marshes would dominate along the stream, with few other herbaceous species remaining on the streambanks. Only remnant patches of seepwillow and burrobrush would be present on terraces. Overflow channels would remain fairly constant, with little change over time in the composition of species.

Theoretically, ecological restoration of this degraded site would require more than simply a manual planting of desirable species, such as cottonwood and willow. Restoration of natural processes is the key to long-term, viable restoration projects, as opposed to attempts to replace vegetative patterns.

Alternately, what if groundwater levels were drastically to drop in the vicinity of the preserve? At what point would we know that this was having a negative effect on the plant community? According to the model (see Table 1), each patch type is located at a certain height above the water table. As the water table began to drop, those patch types that require shallow water tables would be affected first. By monitoring not only the groundwater itself but also the patch types most sensitive to groundwater withdrawal, changes would be detected early on.

A more holistic approach to monitoring might involve mapping all of the patch types within the floodplain and determining the relative proportion of any given patch within the overall community. Regardless of how patches shift positions and move within the floodplain, if their relative proportion remains roughly constant over time the overall community probably is not declining as a result of groundwater withdrawal.

What if the patch types that require the shallowest water tables begin to disappear? Would restoration attempts to replant or reestablish these species be successful if water tables continued to decline? Probably not.

Summary and Recommendations

The place to begin management and restoration planning for riparian communities is literally to get your feet wet. Spend some time making observations on the site to gain a feel for the existing ecological patterns. Try to understand why species are present or absent and what the reasons are for their distribution patterns on the landscape. Identify patch types of similar composition, structure, or density in the overall community.

The collection of pertinent abiotic information will enable a comparison of the physical differences between patch types (i.e., height above the stream or water table, depth of water, or distance from the stream). With these data in hand, the beginnings of a conceptual model for patch types found on the site can be developed from a single, instantaneous "snapshot" of the physical and biotic conditions on the site. Remember, however, that your image of how an ecological system works should be tested through monitoring and observations over time. No models are perfect representations of reality, but they can be useful for helping land managers to comprehend complex ecosystem dynamics.

Wise stewardship of the land has much in common with good medical practice: Take the time required to carefully diagnose the patient's ailments, then treat the cause (process), not the effect (pattern). The most successful treatments begin with a thoughtful and thorough diagnosis.

References

Day, R.T., P.A. Keddy, and J. McNeill. 1988. Fertility and disturbance: a summary model for riverine marsh vegetation. *Ecology* 69(4)1044-54.

Decamps, H. 1984. Biology of regulated rivers in France. In A. Lillehammer and S.J. Saltveit (eds.), *Regulated rivers.* Oslo: Oslo University Press.

Gill, D. 1973. Modification of northern alluvial habitats by river development. *Canadian Geographer* 17:138-53.

Grime, J.P. 1979. *Plant strategies and vegetation processes.* Chichester: John Wiley and Sons.

Hammoad, H.Y. 1972. River bed degradation after closure of dams. *Proceedings of the American Society of Civil Engineers, Journal of Hydraulics Division* 98:591-607.

Heede, B.H. 1986. Balance and adjustment processes in stream and riparian systems. In *Proceedings Wyoming Water 1986 Conference and Streamside Zone Conference*, Casper, Wyoming.

Huston, M. 1979. A general hypothesis of species diversity. *American Naturalist* 113:81-101.

Johnson, R.R., and C.H. Lowe. 1985. On the development of riparian ecology. *Proceedings of First North American Riparian Conference*, Tucson, Arizona.

Mitsch, W.J., M. Straskraba, and S. E. Jorgensen (eds.). 1988. *Wetland modelling: Developments in environmental modelling 12.* New York: Elsevior Science Publishing Co. Inc.

Nilsson, C. 1984. Effect of stream regulation on riparian vegetation. In A. Lillehammer and S.J. Saltveit (eds.), *Regulated rivers.* Oslo: Oslo University Press.

Pautou, G., and H. Decamps. 1985. Ecological interactions between the alluvial forests and hydrology of the Upper Rhone. *Archiv fur Hydrobiologie* 104:13-37.

Pickett, S.T.A., and P.S. White (eds.). 1985. *The ecology of natural disturbance and patch dynamics.* New York: Academic Press.

Richter, B.D. 1991. Unpublished data. On file Hassayampa River Preserve, The Nature Conservancy, Wickenburg, Arizona.

Silvert, W. 1989. *Modelling for managers: Ecological modelling 47.* Amsterdam: Elsevier Science Publishers B.V.

Stanford, J.A., and J.V. Ward. 1986. The Colorado River system. In B.R. Davies and K.F. Walker (eds.), *The ecology of river systems.* Dordrecht, The Netherlands: Dr. W. Junk Publishers.

Stromberg, J.C., D.T. Patten, and B.D. Richter. In Press. *Flood flows and dynamics of Sonoran riparian forests.*

Stromberg, J.C., B.D. Richter, D.T. Patten and L.G. Wolden. 1991. Response of a Sonoran riparian forest to a 10-year return flood. Unpublished manuscript. On file Center for Environmental Studies, Arizona State University, Tempe.

Tilman, D. 1982. *Resource competition and community structure.* Princeton: Princeton University Press.

Ward, J.V. 1989. Riverine-wetland interactions. Freshwater wetlands and wildlife 1989. CONF-8603101, *DOE Symposium Series* No. 61, R.R. Sharitz and J.W. Gibbons (eds.). USDOE Office of Scientific and Technical Information, Oak Ridge, Tennessee.

***Holly E. Richter** formerly was a preserve manager for The Nature Conservancy's Hassayampa River Preserve in Arizona. She now is a consulting ecologist based in Boulder, Colorado. Richter would welcome information from other researchers or land managers on the use of conceptual models for management or restoration of other riparian areas worldwide. Write to her at Box 3514, Lyons, CO 80540 USA.*

Measuring the Economic Values of Riparian Areas: A Case Study

Kristine B. Crandall

In the arid and semiarid regions of the western United States there is a saying: "Whiskey is for drinking, water is for fighting over." That colorful phrase is really another way of saying that survival and growth are inextricably tied to the availability of water. In the American West, the interests vying for a share of the limited available water include rapidly growing cities, agricultural irrigators, mining companies, power plants, Indian tribes, outdoor recreationists, and environmentalists. In developing countries, competing interests for water are especially concerned with resource development, job creation, and establishment of export markets (Dixon and Sherman 1990).

While the market value of water in consumptive uses is readily apparent, the value of recreational and environmental water uses that depend on reliable instream flows and their associated riparian ecosystems is not so easily quantified. Improved water quality, outdoor recreation opportunities, wildlife and fish habitat preservation, and local/regional economic development are potential economic benefits of water allowed to flow instream (Colby 1990), rather than being diverted for a variety of direct economic uses. But such environmental amenities tend to fall into the category of public goods, which, in contrast to the private goods of competitive markets, are not associated with an organized market structure for their allocation. Consumers cannot be prohibited from enjoying and using public goods, and one person's consumption of the good does not necessarily affect another's.

These factors explain why prices associated with public goods do not usually reflect their full value, a situation that makes a meaningful economic comparison between instream uses of water and uses that produce tangible market outputs (e.g., agriculture, stock-watering, and mining) very difficult. This article discusses several methods that economists use to identify and measure the economic values of amenity resources. In so doing, it demonstrates why, from an economic point of view, we should be interested in preserving and restoring riparian ecosystems. A case study is presented to give the reader a feel for the application of such techniques.

Valuation Methods

Economists have developed several methods to measure the economic benefits of "amenity" resources. They include the Travel Cost Method (TCM), the Contingent Value Method (CVM), and local economic impact analysis. These techniques are used primarily to look at recreational and tourism values, but CVM also is useful for looking at nonconsumptive and future values (for a description of different values produced by natural areas, see Dixon and Sherman 1990). The Travel Cost Method and Contingent Value Method piece together various kinds of information to estimate "demand functions" for environmental goods. The demand function allows estimation of total economic benefits provided by the flowing stream and/or riparian environment. Loomis (1987) examines the ability of TCM and CVM to estimate marginal values of instream flow and optimal flow levels, and cites several empirical studies that have successfully used these methods.

TCM is used specifically to value outdoor recreation sites. It's underlying premise is that visitors react to travel costs as they would to different levels of entry fees at recreation areas. As formulated by Clawson and Knetsch (1966), travel costs are calculated for different zones of visitor origin. These costs are assumed to increase and visits per capita to decrease with increasing distance of the zone from the site. Visitation rates for each zone are regressed on travel costs, substitute site information, income, and other socioeconomic variables. The re-estimation of visitation rates for incrementally higher travel costs generates a demand function for the site.

The resulting aggregate demand function is used to measure total economic benefits in the form of consumer surplus, which is identified as the difference between the consumer's willingness to pay for a good and his or her actual expenditure for the good. This amount reflects a benefit to consumers, as they are paying less than they would actually be willing to pay. The entire area considered under the demand function is the total consumer surplus for the site.

The Contingent Value Method (CVM) is a survey method that simulates a market for an environmental good through the presentation of a hypothetical scenario. The scenario presents incremental changes in the quality or quantity of the good, and respondents are asked to give their maximum willingness to pay (WTP) for the specified changes. Mitchell and Carson (1989) describe the methodology and the integral parts of a CVM survey, which they break down into three components: (1) a detailed description of the environmental good and the proposed change(s), (2) the elicitation of the WTP amount, and (3) questions about respondent characteristics.

In the case of instream flow and riparian areas, a description of the good would involve a verbal and, ideally, a visual presentation of various possible levels of streamflow and of the composition of the associated riparian ecosystem. In the next step, respondents would be asked to state their maximum WTP for the delineated change. A variety of techniques have been developed for this procedure, differing in the mode of payment that the respondent can use and in the question format itself (Mitchell and Carson 1989). Information on respondent sociodemographic characteristics also is collected and used in the statistical analysis to interpret WTP results. Through statistical analysis of incremental

WTP responses, a demand specification for the streamflow and/or riparian site is generated, enabling estimation of marginal benefits and total change in consumer surplus.

One key difference between these two techniques is that the willingness-to-pay (WTP) response represents a direct, self-reported transaction in the case of the Contingent Value Method, while the Travel Cost Method uses observed behavior to infer WTP or consumer surplus values. Like TCM, CVM is capable of investigating user benefits, but it also can be applied to nonusers and can measure option and existence values, which prior studies have shown to be a substantial part of an environmental amenity's total value (see Stoll and Johnson 1984, Sanders et al. 1990).

Some concern has been expressed about CVM's reliability, given that it presents respondents with a simulated market scenario; that is, one that they have had no experience with. Cummings et al. (1986) explore this topic, and recognize that biased WTP responses may occur when care is not taken in constructing the survey instrument.

Local economic impacts differ from the other two approaches in that they do not measure social benefits of a natural area, but instead estimate the revenues generated within the local economy as a result of purchases made by site visitors. Visitors participating in activities that depend on reliable streamflows and riparian habitat quite often come from outside the local community, thereby bringing in "new" economic activity. Such revenues are of great interest to local businesses, chambers of commerce, and residents. For countries such as Kenya, Tanzania, Costa Rica, and Nepal, visitors to nature preserves and game parks produce significant tourist revenues. The importance of nature tourism and the economic relationship between protection of natural areas and consumptive land uses is discussed by Dixon and Sherman (1990) and by Whelan (1991).

Local economic impacts are both direct and indirect. Direct impacts result from the increased revenues that accrue to the gas stations, restaurants, hotels, gift shops, and other businesses from recreationists' expenditures. Indirect impacts include the secondary purchases made by local businesses and intermediate sectors as a result of initial (tourist) expenditures. Some of these secondary purchases are from local businesses, while others are purchases from outside the area and thus represent leakages. The increased demand among those sectors affected by recreational spending leads to increased household income and employment, which in turn promotes additional economic activity, often called induced effects (Bergstrom et al. 1990). A schematic of these effects is presented in Figure 1.

Multipliers are used to assess the magnitude of indirect and induced effects. Multipliers are obtained through the use of input-output models that trace initial expenditures through the different economic sectors. Stevens and Rose (1985) define a multiplier as the ratio of higher order effects and direct effects; in other words, multiplying one dollar of visitor spending by the appropriate multiplier gives the total direct, indirect, and induced economic effects for the

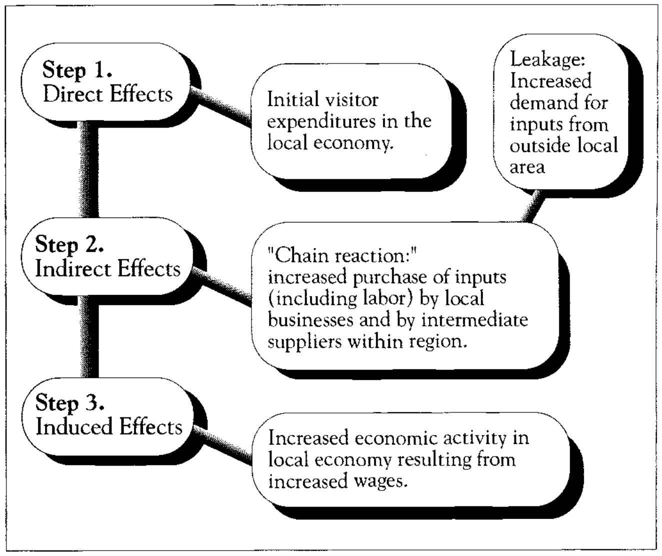


Figure 1. Schematic representation of multiplier effects.

specified community or region. The amount of transacting that occurs among the economic sectors within the local region determines how large the multiplier will be.

Case Study: The Hassayampa River Preserve

What follows is a description of a study that employed TCM, CVM, and local economic impact analysis in an economic assessment of The Nature Conservancy's Hassayampa River Preserve. The study used data collected from a survey of site visitors to compare the application of the three techniques and to estimate and compare the economic benefits of the site.

The Hassayampa Preserve is located in south-central Arizona, 7 km southeast of Wickenburg and about 85 km northwest of Phoenix. It encompasses one of Arizona's last extensive cottonwood-willow forests, which winds its way along a perennial stretch of the Hassayampa River. As with all Nature Conservancy lands, the Hassayampa Preserve is managed for the purpose of protecting critical natural habitat. Several wildlife species, including the lowland leopard frog, Arizona Gilbert skink, and zone-tailed hawk, are dependent on the Hassayampa's riparian habitat for their survival.

The Hassayampa Preserve is open to the public during daylight hours, with visitors being restricted to two trails. It lures birdwatchers, nature lovers, and escapees from the desert heat to its lush, moist riparian environment.

A total of 118 Preserve visitors were surveyed in the spring of 1990 (out of 147 asked to respond, yielding an 80-percent response rate). The survey's questions were designed to gather data for implementation of the three valuation techniques. Visitors were asked about their purchases in the nearby community, trip characteristics, and their willingness to pay for different riparian habitat conditions. The survey also gathered data on general visitor attitudes and demographics.

The zonal method was used in the TCM analysis, since a majority of visitors were visiting the Hassayampa for the first time. In addition, a decision was made to use only Arizona residents because no out-of-state residents made a trip to Arizona solely to visit the Preserve. Similarly, only Arizonans whose primary purpose for the trip was a Preserve visit were included in the study. Both of these restrictions were necessary because the TCM requires a clear definition of travel costs as they relate to visiting a particular site.

Regression analysis provided the estimation of a trip demand function that contained the following variables within a semilog functional form:

Visit = f (Travel Cost, Age, Income)

The dependent variable *Visit* represents Preserve visits per capita from each zone. *Travel Cost* is composed of a car operation/ownership expense of US$0.33 per mile (American Automobile Association 1990) and a travel time value that employed 50 percent of the average zonal wage rate. *Travel Cost*, *Age*, and *Income* are all based on averages for each postal zip code zone in the analysis, of which there were 39. The regression coefficient on *Travel Cost* was significant and negative, which is consistent with TCM's assumption about visitor behavior. The R-squared for the semilog model specification is .47, and the F-statistic value of 7.59 is significant at the .05 level.

The final step of the TCM analysis involved the estimation of an aggregate demand function relating price to total visits. Incremental price increases were added to each zone's travel cost, and visits per capita and visits over all zones were re-estimated. Integration of the area under the aggregate demand function results in an estimated annual consumer surplus measure for the site of US$613,360.

For the survey's CVM scenario, the respondent was shown a photoboard and "ladder" depicting two different levels of riparian habitat quality. The regularity and quantity of streamflow were the decisive factors that influenced the riparian area's diversity of vegetation and wildlife species. The respondent was told to assume that the status quo was level B (intermittent streamflow) and then was asked to indicate his or her willingness to pay (WTP) to restore the site to level A (perennial streamflow). A payment card provided a range of payment choices; payment was to be in the form of increased taxes paid into a public fund for restoration of riparian areas.

The CVM analysis produced data representing only one incremental change in riparian area quality (from level B to level A), and so a marginal benefit curve could not be constructed. Instead, the average individual WTP value of US$65 was used to estimate the total annual WTP for restoration of a riparian site from level B to level A. The welfare measure of such a change was estimated to be US$520,000, based on an estimated 8,000 annual visitors to the Preserve (Crandall 1991).

In one section of the survey, respondents were asked to record the purchases they made in Wickenburg that were directly related to their visit to the Hassayampa Preserve. The average individual expenditures in Wickenburg totaled US$6.48, an amount made up of purchases of gas, groceries, restaurant services, and lodging. For the approximately 8,000 visitors in 1990, the estimated direct local economic impact was US$51,840. Indirect impacts were estimated using Type III output multipliers obtained from a county IMPLAN model (Bergstrom et al. 1990). Multipliers were derived for the food/beverage and restaurant services, lodging, and other retail sectors. The total local economic impacts, including both direct and indirect effects, were approximately US$88,000 in 1990. The selected multipliers and actual calculation of this result is presented in Table 1.

Discussion and Summary

The challenge of valuing ecologically rich riparian areas using the methodologies described in this article raises some interesting points. The three approaches effectively generated value estimates, but how can these results be used and what are their policy implications?

First, it is important to note that the economic activity estimated by local economic impact analysis cannot accurately be classified as a "benefit" of the Hassayampa River Preserve, since the costs of supplying these goods and services have not been accounted for. The Hassayampa study's local economic impact analysis result of US$88,000 is a small part of Wickenburg's income from tourism, which includes revenues from some fairly exclusive and high-priced resorts. It is, however, important to note that 70 percent of the respondents were visiting the Preserve for the first time, a signal to Wickenburg businesses that new visitors are being drawn to the area by the Preserve.

Second, the consumer surplus measures provided by TCM and CVM are not widely understood among noneconomists; however, they are crucial in the case of public goods, where a consumer partakes in an activity without being charged a price reflecting the worth of that experience. Measures like the Hassayampa zonal TCM consumer surplus amount of US$613,360 can provide useful information for land managers of outdoor recreation areas. The relative value of a site or potential site in terms of visitor benefits assists in determining how to manage outdoor recreation sites. TCM models also can predict the effects that certain decisions, such as increasing entry fees, will have on visitation.

Finally, in conjunction with the TCM consumer surplus result, the study's CVM total WTP of US$528,000 provides relative information on how depletion of a riparian site might affect the original consumer surplus. Allowing the actual consumer surplus of US$613,360 for the Hassayampa to represent level A, then restoration of a site from level B to level A would result in a potential 80-percent increase in site user benefits, which is a significant difference.

In terms of policy implications, restoration from an intermittent to a perennial streamflow is not presently an issue at the Hassayampa Preserve, since it is already a good example of a site at level A. (The Nature Conservancy has secured instream flow water rights for this stretch of the Hassayampa River.) However, these results have implica-

Table 1. Local economic impact calculations for the Hassayampa River Preserve Study.

Economic Sector	Direct Impacts	Multiplier	Total Impacts
Food/Beverage and Restaurant services	$21,280.00	1.6	$34,048.00
Lodging	27,360.00	1.79	48,974.40
Gas (other retail)	3,200.00	1.63	5,216.00
Total	$51,840.00		$88,238.40

tions for other riparian areas that do not have the same degree of protection. Given increased competition for limited water resources, flowing streams and riparian areas that have not been fully protected face potentially large losses in user benefits and, therefore, in contributions made by visitors to local economies. On a worldwide scale, as the total demand for freshwater resources increases, including a 45-percent increase in land area under irrigation (UNEP 1991), the economic benefits conferred by the presence of viable riparian areas becomes of critical importance.

In the case of Arizona, such results provide impetus for the establishment of a state water policy that more readily grants instream flow interests access to the process of water rights allocation. Water policies in general should be developed that stress designation of instream flow rights and protection of riparian areas.

Another implication relates to rural economic development opportunities in the form of nonconsumptive land and water uses. As rural communities in natural resource-rich regions struggle to achieve a more diverse, stable, and environmentally sustainable economic base than they have had in the past, the importance of water-based recreation as a key economic activity will increase. The identifiable positive economic contributions stemming from these kinds of outdoor recreation sites should be included in land use planning and rural economic development strategies.

In summary, the results obtained from the three economic valuation techniques presented in this paper provide information that, in the case of public goods and amenity resources like instream flow and riparian areas, is not otherwise available. As shown by the Hassayampa River Preserve case study, the methods can be complementary, in that they each contribute a different piece of the puzzle. The Travel Cost Method (TCM) provided an account of total site benefits. An incremental change in riparian habitat quality as a function of streamflow changes was addressed by the Contingent Value Method (CVM). Finally , the local economic impact analysis allowed for examination of the Hassayampa River Preserve within the economic framework of the local community of Wickenburg; in other words, its benefits to local residents and businesses. The values that these methods measure confer an economic status on riparian ecosystems, and thus provide a strong economic argument for their protection.

References

American Automobile Association (AAA). 1990. *Your driving costs.* Heathrow, FL: AAA.

Bergstrom, J. C., H. K. Cordell, G. A. Ashley, and A. E. Watson. 1990. Economic impacts of recreational spending on rural areas: A case study. *Economic Development Quarterly* 4(1):29-39.

Clawson, M., and J. Knetsch. 1966. *Economics of outdoor recreation.* Baltimore: Johns Hopkins University Press.

Colby, B. G. 1990. Enhancing instream flow benefits in anera of water marketing. *Water Resources Research* 26(6):1113-20.

Crandall, K. B. 1991. Assessing the economic benefits of riparian areas. In *Riparian issues: An interdisciplinary symposium on Arizona's in-stream flows.* Tucson: Arizona Hydrologic Society and Soil and Water Conservation Society.

Cummings, R. G., D. S. Brookshire, and W. D. Schulze. 1986.*Valuing environmental goods: An assessment of the Contingent Valuation Method.* Totowa, NJ: Rowman and Allanheld.

Dixon, J. A. and P. B. Sherman. 1990. *Economics of protected areas: A new look at benefits and costs.* Covelo, CA: Island Press.

Loomis, J. B. 1987. The economic value of instream flow: Methodology and benefit estimates for optimum flows. *Journal of Environmental Management* 24(2):169-79.

Mitchell, R., and R. Carson. 1989. *Using surveys to value public goods: The Contingent Valuation Method.* Washington, DC: Resources for the Future.

Sanders, L. D., R. G. Walsh, and J. B. Loomis. 1990. Toward empirical estimation of the total value of protecting rivers. *Water Resources Research* 26(7):1345-57.

Stevens, B., and A. Rose. 1985. Regional input-output methods for tourism impact analysis. In *Assessing the economic impacts of recreation and tourism.* Asheville, NC: USDA Forest Service Southeastern Forest Experiment Station.

Stoll, J. R. and L. A. Johnson. 1984. Concepts of value, nonmarket valuation and the case of the whooping crane. In *Transactions of the 49th North American wildlife and natural resources conference.* Washington, DC: Wildlife Management Institute.

United Nations Environment Programme (UNEP). 1991. *Environmental data report, 1991-92.* London: UNEP.

Whelan, T. (ed.). 1991. *Nature tourism.* Washington, DC: Island Press.

***Kristine Crandall** holds a Master's Degree in natural resource economics from The University of Arizona, where she is a Research Specialist in the Department of Agricultural Economics. She specializes in the economic valuation of natural areas, instream uses of water, and the contributions of these resources to local economies.*

Some Principles and Practices of Desert Revegetation Seeding

Dan James

Drastically disturbed lands can be managed by two methods: action and nonaction. Nonaction often is chosen because of its perceived low cost, but taking action to revegetate a site after disturbance often will prove less costly and more beneficial in the long term.

Leaving a disturbed site barren after activities such as road construction or mining can lead to soil erosion, blowing dust, weed infestation, and loss of livestock forage and wildlife habitat. Later, cleanup costs and attempts to revegetate weed-infested sites can prove to be expensive or impractical.

Revegetation as Restoration

Revegetation seeding often has been merely seeding with anything that will work to establish plants, regardless of long-term goals or origin of plants selected. The use of exotic plant material in attempts to solve the problem of plant establishment on harsh sites remains widespread.

Revegetation should be considered a part of the larger process of restoration, often called ecological restoration.

Ideally, ecological restoration is the process of returning disturbed land to a prior natural state; in practice, getting as close to that condition as possible is the goal. Although plants will do much to change and stabilize a disturbed site, restoration involves more than revegetation alone, and may include recontouring and reshaping the land, replacement of surface soils, and creating features such as boulder piles. It is much more than landscaping.

The practice of revegetation itself draws upon many disciplines: ecology (which is chief among them), botany, agronomy, and edaphology are all involved and are interrelated. The factors determining a population of plants are interacting and dynamic. Among them are the concepts of carrying capacity and limiting factors, which together should be heavily relied upon; environmental and site condition factors, such as climate, soils, aspect, and topography, which will partly determine species composition and abundance on a site; and processes such as germination, growth rate, competition, succession, and natural regeneration.

Site Preparation

Specific site conditions will determine carrying capacity, or plant abundance and distribution. Site conditions such as slope, soil properties, weed potential, and accessibility, which often will need to be modified to create an environment conducive to establishment of the desired plant population, will determine method and material use. Schedule and budget also will play a role.

The degree of slope often prescribes the method of site preparation. Steeper slopes will be more difficult or impractical to prepare with heavy equipment. The irony is that steep slopes often require better soil preparation, in that they often are hard and compact cutbanks. Heavy crawler tractors equipped with ripper blades often are used to break up compacted soil and to create contour furrows across the slope. It is dangerous to operate across a slope that is greater than 2.5:1 (run : rise). A crawler tractor can rip up or down some steeper slopes where cross-slope operation is not possible, although this kind of ripping will cause furrows to run downslope and create an erosion hazard. This may be corrected by placing checks across the ripped furrows using the dozer blade. On very steep slopes or where deep ripping is not practical, a heavy anchor chain equipped with crossbars on the links can be rolled across the slope to break up hard soil and to create a roughened or furrowed surface.

If soil replacement is necessary on drastic sites, such as some mine tailings, it will be more difficult to place the soil and to maintain it on a steep slope.

Soil properties such as erosiveness, compaction, surface roughness, structure, texture, fertility, and water infiltration and holding capacity may require modification. These factors often are interacting and play a significant determining role in potential plant distribution and abundance. Soil compaction probably is the main impediment to plant growth on disturbed sites. Heavy equipment operations, such as those carried out during construction, actually cause soil compaction, while deep cuts into the soil expose buried compacted subsoils. A revegetation project may fail or succeed because of the nature of soil compaction on the site.

Good tillage techniques will break up compacted soil—heavy crawler tractors often are used—and create a roughened or furrowed surface that helps in the capture, percolation, and retention of water; this is a very important factor for plant establishment, in that moisture usually is the major limiting factor in arid environments. Ripping also provides an improved environment for root growth and the resulting contour furrow effect has the potential to reduce the erosiveness of the soil. Soil should not be prepared by machinery such as rotary tillers, which could cause the structure to become pulverized; excessive tillage of any kind should be avoided for this reason. Operation of equipment on wet or very dry soils can cause compaction or pulverization.

Although modification of soil fertility often is necessary and desirable, soil should be tested prior to nutrient modification to determine required amendments. Typical agronomy practices show most desert soils to be deficient in nitrogen and available phosphorus. Drastically disturbed sites with exposed lower soil profiles have even lower nutrient levels. Most desert species benefit from the addition of commonly available fertilizers. The standard treatment for increasing fertility on disturbed sites in the Sonoran Desert of the United States and Mexico is to apply granular ammonium phosphate (16-20-0) at a minimum of 40 lbs. of actual nitrogen and 60 lbs of phosphorus per acre. This appears to be only a minimum, however, especially on deep subsoils.

Double the amount has been applied on certain sites to good effect.

Some sites have been supplemented with organic, humus-based fertilizers combined with slow-release, all-purpose nutrient formulations. Results have been favorable when this combination is used at rates of 1,000 lbs. per acre of 50-percent humus base with a 5-3-1 (N-P-K) formulation. Growth appears to be greater than would be expected from adding just the basic formulation. Some organic fertilizers contain added microorganisms, which may be the reason they are effective on severe sites. Symbiotic relationships of microorganisms with vascular plants are well documented, but the use of microorganisms in revegetation remains an area of needed research.

Sites stripped of surface vegetation but not of surface soils may require no added nutrients. Surface soils contain microorganisms, residual nutrients, and organic matter. Surface soils can be recapped over a disturbed site, although this practice should be avoided if the surface soil contains undesirable weed seed, such as that of Russian thistle (*Salsola* spp).

Weeds can be a significant factor in competition with desired vegetation. Common problem weed species in Sonoran Desert revegetation include Russian thistle (tumbleweed), wild barley (*Hordeum* spp.), cheeseweed (*Malva* spp.), mustard (*Brassica* spp.), London rocket (*Sisymbrium irio*; pigweed), *Amaranthus* spp., and telegraph weed (*Heterotheca* spp.). Some seedings have failed because of weed competition. Many have been degraded by weed growth. And if weeds are a potential problem, remember that adding fertilizer can encourage weed growth and competition.

Newly disturbed sites left fallow and open to initial weed growth can be deep-tilled or plowed to bury recent generations of surface weed seed populations. Most weed seed buried deeper than two inches will not emerge. Old disturbed sites, such as abandoned farmland, can have significantly high populations and many generations of dormant weed seed within the soil profile; in this case, turning the soil will not reduce the problem.

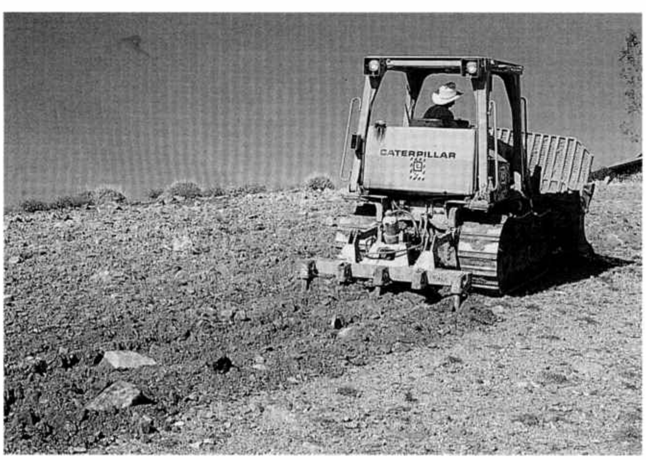
Several other methods of weed control have been tried. Pre-irrigations have been used to bring up weed seedlings, but this has not worked on severely infested soil, owing to the many and varied stages of dormant seed and to variability in germination characteristics over time. Soil fumigants may be effective on very controlled sites, but fumigation kills all living organisms in the soil profile. It is not a recommended technique, for a variety of reasons: beneficial microorganisms are killed, tree roots from neighboring properties can be killed, and the chemicals are dangerous to handle. The best way to avoid a weed problem is to prepare and seed before weeds and weed seed populations build up.

Sites to be restored usually should be prepared just prior to seeding. Tillage will leave a soft friable surface in which seeds can be easily placed by a variety of seeding methods. If a site is prepared too far ahead of seeding, it may weather and crust over, leaving a sealed soil layer between the seed and a favorable germination environment.

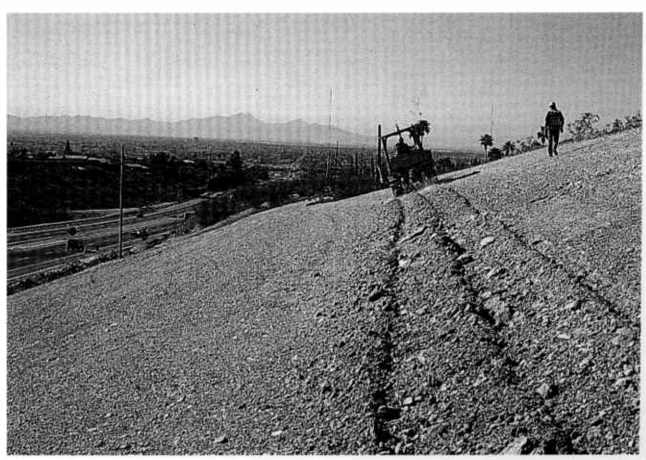
In general, then, deep, friable, fertile soils will produce greater growth and better drought tolerance than will hard, compacted, infertile soils. This is not to say that native desert species require the site preparation usually given agricultural and horticultural crops; many are able to establish and grow on extreme sites. Owing to the wide variability in environmental extremes such as temperature and available moisture, however, experience has shown that it is best to prepare the site to increase chances of success. Site preparation usually is low cost in relation to other aspects of revegetation.

SPECIES SELECTION

Many factors and considerations are involved in species selection for revegetation projects. (1) Species should be well adapted to site conditions or have a history of successful use; exotic species potentially detrimental to local or surrounding environments should be avoided. (2) Revegetation for ecological restoration should use native species exclusively. (3) Mixes of species should always be used to foster diversity. (4) Seeding rates, growth forms, species compatibility, and plant longevity should be considered.



Tillage on an old cut slope; heavy crawler tractors are required to adequately break the hard soil.



Furrows cut with crawler tractor rippers capture moisture and reduce runoff erosion.

Mine overburden site in the Sonoran Desert prior to reseeding.

Once objectives have been determined, survey the site to determine which species are best adapted to site conditions. Local natural vegetation will give an indication of what is adapted to the local climate. (Sites often are so severely degraded in relation to surrounding natural areas that significant site preparation is required).

Site conditions such as slope, soil properties, weeds, and potential wildlife problems play a role in species selection. Grasses are very good at stabilizing soils and controlling erosion, as in the case of steep slopes. Grasses typically are very competitive with weeds, and weeds are one of the major limiting factors in establishing native plants from seed. A site may be capable of supporting native grasses even though native grasses are not now abundant, owing to past site abuses. Reintroducing native grasses can have a beneficial effect well beyond the boundaries of the site being revegetated. Exotic species, on the other hand, only look good to the untrained eye. Some species exotic to the Sonoran Desert, such as Lehmanns lovegrass (*Eragrostis lehmanniana*), have appeared to be quite successful under a variety of conditions. Experience has shown, however, that the species tends to dominate and remains competitive to the detriment of more desirable and diverse native species.

Steep slopes may be very visible, and in that case will require addition of shrubby species in order to blend the site with surrounding areas. Some plants are adapted to certain soil textures. Four-wing saltbush (*Atriplex canescens*) is well adapted to clay soils, for example, while brittlebush (*Encelia farinosa*) performs poorly on clay soils. If existing weeds are a factor, then fast-growing, competitive plants such as mesquite (*Prosopis* spp.) and saltbush should be considered.

As a rule, then, prefer native species to exotic species. Many thousands of acres worldwide have been seeded with exotic grasses in attempts to improve rangeland degraded by overgrazing. This is not ecological restoration. Introducing these exotics may, in fact, reduce the chances for natural vegetation to return.

Revegetation seed mixes should be diverse. Not only will diversity give a better chance of establishing vegetation, it also produces a healthier and better balanced environment. A simple survey of any natural desert area will reveal dozens of plant species coexisting, and it is not unusual for 20 species to be used in revegetation mixes. A combination of annual and perennial species is recommended. In the Sonoran Desert, for example, annuals such as Indian wheat (*Plantago insularis*) and Mexican poppy (*Escholtzia mexicana*) germinate quickly and give fast initial cover. Slow-establishing perennials such as creosote (*Larrea divaricata*) and whitethorn acacia (*Acacia constricta*) do not give fast coverage, but they lend essential diversity to the restored plant community. It appears, too, that many perennials are more successful in diverse mixes including annuals, and observation has shown that a more diverse mix increases the chances of each individual species becoming established.

The same site being hydroseeded with a one-step application of grasses and shrubs (August 1982).

Species diversity also confers benefits in terms of site stabilization, erosion control, and wildlife habitat improvement. A wide fluctuation in plant numbers is less likely with diverse mixes and there is less chance of a site becoming decadent, as often occurs with solid stands of African lovegrasses. Root biomass and structure will be diverse, too, giving better overall soil erosion control. Wildlife may well be attracted by increased niche development and more varied forage and growth forms.

Seed mixes should be carefully designed to avoid problems of interspecific and intraspecific competition. The growth characteristics of annuals and many grass species can make them very competitive with slower growing perennials. The annual Mediterranean grass (*Schismus* spp.), which has been introduced well beyond its natural range, severely inhibits the establishment and growth of most other species. Perennials such as the African lovegrasses (*Eragrostis* spp.) also appear to inhibit establishment of other species; like annuals, their initial growth can be fast and smothering, quickly dominating a site. Slower-establishing species are out-competed.

Competitiveness becomes even more important when seed rates are considered. Many annuals and grasses are very fine-seeded. Mediterranean grass and Lehmanns lovegrass, for example, both have seed counts exceeding 5 million to the pound. A cupful of seed of these species sown over one acre equates to more than 50 seeds per square foot. Seed production per unit area also is very high. If competitive species are used, seed rates should be low, especially if the species is fine-seeded. In fact, too high a rate of any species should be avoided; not only will the plants compete with other desired species, they will reduce their own growth potential and drought tolerance. Some desirable target species seeded too heavily have created decadent stands or monocultures, even though very diverse mixes were used. This has occurred in the Sonoran Desert with brittlebush, various species of saltbush, and desert marigold (*Baileya multiradiata*).

Budgets also must be considered in species selection. The cost and benefits of the species used should be considered. Selection should be based on a history of successful use; using expensive species without a history of use can be a waste of money. This is not to say that untried species should never be used. Use such species on a small scale first, to determine their cost effectiveness.

When to Seed

When to seed is one of the most basic factors to consider when planning a revegetation project. The question of when to seed comes from the fact that different species of plants respond differently to seasonal weather variations. Plants often are classified as warm or cool season species, and many

The same site three years after seeding; herbaceous species are dominant but shrubs are beginning to appear.

species are distinctly obligate warm or cool season species. Some are facultative, which means they respond to stimuli not necessarily seasonal. Even within classifications of obligate cool or warm season species, there is variation. Purple three-awn (*Aristida purpurea*), for example, is a warm season species that leafs out early in the spring, quickly responding to residual winter moisture. It then flowers and sets seed before green-up of many other warm season species.

Experience has shown that both warm and cool season species can be established simultaneously during mild periods between summer and winter. The irony is that these periods typically are the driest periods of the year in the Sonoran Desert. Diverse stands of warm and cool season species have been established with irrigation during the September-October period and in the March-April period.

With the bimodal rainfall pattern characteristic of the Sonoran Desert, establishment typically occurs in the winter rainy period for some species and in the summer rainy period for others. More than 12 years of experience with seeding for revegetation in the Sonoran Desert suggests that the summer rainy period may be of greater importance for plant establishment than the winter period. (This may be because there is a greater diversity of warm season species in the Sonoran Desert than of cool season species).

Owing to highly variable rainfall patterns in arid and semiarid lands worldwide, a site should not be left barren while waiting for an optimum time to seed. For dry land seeding, it is better management to use good techniques, diverse seed mixes, and appropriate materials to seed and stabilize a site early, thus creating a long-lasting environment conducive to establishment when rain finally comes.

Time of year to seed also may be determined by the potential species of on-site weeds. A site severely infested with Russian thistle, for example, should be seeded in the summer, as Russian thistle is primarily a cool season establisher.

Seeding Methods

Several criteria will determine the seeding method to be employed. The objective is to place the seed in a stable environment conducive to germination and emergence. A stable environment is one in which soil movement is limited, in which rainfall will not wash the seed away, in which wind will not blow the seed away, and in which moisture and temperature variations are relatively low. Birds, insects, and other animals should not have easy access to the seeds. An environment conducive to germination and emergence is one that retains available moisture, that does not form a hard, crusted surface, and that allows relatively low fluctuations in moisture and temperature.

The soil environment may have natural attributes conducive to germination and emergence, or it may need to

The same site eight years after seeding; white thorn acacia and velvet mesquite are dominant but an herbaceous understory remains.

Broadcast seeding often is more practical and more effective than drill seeding, but hydroseeding is emerging as the best method of revegetation seeding in arid and semiarid regions.

be improved by soil and site preparation, seeding techniques, and surface mulching. These processes are interrelated.

Two basic methods are used for seeding: drill seeding and broadcast seeding. Both methods have advantages and disadvantages. Hydroseeding, a specialized form of broadcast seeding, has its own special attributes. Seed drills for revegetation projects usually are based on the same principles as the grain drills used to plant such crops as wheat, although they usually are designed to accommodate a wider range of seed types. They may have up to three boxes (all adjustable for seed sizes and rates), larger delivery tubes, and disc openers to place the seed at a desired depth. Some are equipped with chisels or coulter discs for breaking soil ahead of seed placement.

Some revegetation seed drills are quite sophisticated. Their usual advantage over broadcast seeding is that seed is placed at a specific depth in the soil, but they have distinct limitations that make them impractical on most revegetation projects in the Sonoran Desert. This is owing to several factors. One is that many desert revegetation sites are rough and/or rocky. Even on rough sites with few rocks—and remember that a rough final grade usually is desired on revegetation sites, owing to the resulting increase in microhabitat—the drill can be bounced around severely enough to damage it and the jolting will cause seed to be poorly placed. If rocks are present or soil is hard, the drill can be severely damaged, even if chisel drills and spring mounted mechanisms are used. Another factor to bear in mind is the diverse size, shape, and structure of desert seeds. A large number of desirable species will not pass through the metering mechanism of even the most specialized drills. A further disadvantage is that small seeds and large seeds are placed at the same depth, which usually is not the optimum depth and may cause detrimental seedling competition. And many sites are steep and inaccessible to a tractor-mounted drill.

Broadcasting a diverse seed mix on rough surfaces usually is more practical, and possibly more effective, than drill seeding, although uneven distribution may be a problem and wind may blow light seed away, especially if hand-sown. Broadcast seed may be lightly harrowed or rolled in with a cultipacker if seed placement is a concern. Dry broadcasting on steep slopes may be impossible; if done anyway, many seeds may not achieve proper placement.

Most of the seeding being done now in the U.S. employs hydroseeders. The hydroseeder is very versatile and can far exceed the limitations of drill or dry broadcast seeding.

As the name implies, hydroseeding is accomplished with water. The machine is like a specialized water truck with internal tank agitators and a pumping system capable of spraying a slurry of seed, mulch, fertilizer and other materials over a specified area. Seed and other materials can be more evenly spread by hydroseeding than by any other method. With the use of hoses, seed can be sprayed on steep slopes and other areas inaccessible to mechanical equipment. Seeding can be done on windy days. And when hydromulch fibers, fertilizers, tackifiers, and other amendments are mixed as a tank slurry and applied over prepared soil—a process known as hydromulching—a germination environment can be created beyond comparison with that fostered by other seeding methods. (The terms hydroseeding and hydromulching often are used interchangeably.)

The hydromulch slurry, if composed of specific types and quantities of materials and sprayed over well prepared roughened sites with loose surface soil, meets many of the criteria that define a stable environment conducive to germination and emergence. The slurry sprayed over loose soil combines mulch and soil to a depth of one-half inch. This mulch/soil layer is resistant to erosion. If quality materials are used, it will move very little with rainfall and virtually not at all with wind. Seed will not move because it is in ideal contact with the soil/mulch matrix. Tackifiers are used in the slurry as adhesives to increase the mulch's resistance to erosion. Birds, insects, and other wildlife have difficulty finding and removing the seed. The mulch material reduces surface crusting caused by rainfall impaction. Moisture softens the mulch/soil layer, allowing water percolation and seedling emergence. Seed placement is excellent, in that the surface soil/mulch layer meets the depth requirement for nearly all desert seeds.

The basic materials used in hydroseeding, other than seed, are mulch, tackifier, and fertilizers.

Mulch materials produced solely for the hydroseed industry are highly engineered; some are more effective than others. Among the better hydromulches are virgin wood fibers from the byproduct wood chips of the lumber industry. Other materials, such as waste paper, sawdust, wood shavings, and grass clippings, have proven to be only about 60 percent as effective in creating a germination environment. Waste paper tends to flatten, wash out, and compact; the other types in this group lack integrity and wash out easily.

Tackifiers, too, come in a wide range of material types. Some have very effective adhesive and cohesive qualities. Others are very poor. Two of the better materials are plantago mucilage and guar-based mucilage. Plantago mucilage is derived from Indian wheat (*Plantago insularis*).

It is a powder that, when mixed with water, forms a sticky, gel-like glue. Guar (*Lyamopsis tetragonoloba*) is similar, but it has been known to be difficult to mix, sometimes forming gel-like balls in water. Tackifiers should be applied to impart good binding characteristics to the slurry as it sets up. Excessive amounts should not be used, as seedling emergence can be impaired.

A wide range of fertilizer types is available. Starter fertilizers usually are used in hydromulch slurry. Site conditions should be considered when selecting a fertilizer. Ammonium phosphate is standard, but slow-release fertilizers and organic types should be considered. If possible, it is better to apply fertilizer to the site during soil preparation. Working the fertilizer into the soil helps place nutrients at the root zone and reduces loss due to vaporization and washing.

SURFACE MULCHING

The objective of surface mulching is to stabilize the surface soil and to augment the seed germination and establishment environment. Surface mulches modify moisture and temperature variations, reduce surface crusting from rainfall, and reduce soil erosion. Experience has shown that surface mulching significantly increases germination and establishment of seedlings.

Site conditions, aesthetic appeal, and cost effectiveness are determining factors in mulch selection. A variety of materials is available, offering a wide range of costs, attributes, and effectiveness. Surface mulches include hydromulch fibers, straw, gravel, and many types of erosion control blankets. Hydromulch and straw mulch are the most extensively used, owing to their low cost and effectiveness.

Hydromulch used in the seeding process is considered a surface mulch. Hydromulch is in intimate contact with the soil and seed. This is of definite benefit to seed germination but of less use in modifying moisture and temperature fluctuations in the soil profile; heat fluctuation and moisture loss from the soil typically are greater than with the use of some other materials. Hydromulch, therefore, is very good for germination but less so for seedling establishment. Because hydromulch generally gives good coverage and adheres to the soil, making it a very good surface stabilizer, the greatest benefit of hydromulch can be derived from its use in combination with other mulch materials, particularly straw. Tackifiers added to the process increase mulch effectiveness. Hydromulch lasts on site in excess of two years.

Although often compared, straw mulch differs considerably from hydromulch. The chief difference is that straw mulch functions more as an insulator than does hydromulch. This insulating factor modifies soil moisture and temperature fluctuations and increases retention of soil moisture, yielding increased germination and seedling establishment. Properly applied straw mulch also reduces soil erosion considerably. Covering hydromulched seed with straw mulch and affixing the straw has given excellent results at relatively low cost. Straw affixed with an additional layer of hydromulch and tackifier slurry currently is the most effective treatment for revegetation seeding, given its relatively low cost. Cost can be reduced further by crimp-discing the straw, although wind may remove more straw with this method than with tacking. Crimping and tacking straw are highly effective in combination. This treatment can last in excess of two years.

Gravel mulch sometimes is used where surface rill erosion is anticipated. Typically, a layer of gravel is spread from one to two inches deep over seeded soils. Gravel mulch is long lasting, but its cost is relatively high. Plant establishment can be highly variable, owing to increased temperature of the gravel during hot weather, and seedling emergence may be impaired in some species on some sites.

Many types of erosion control blankets are available, but the most commonly used types are jute netting, excelsior, woven straw, and woven coconut fibers. They are graded on tensile strength and longevity or decay rate; these factors may or may not relate to seedling establishment. They are very expensive compared with straw mulch and hydromulching, and they typically are considerably inferior to well affixed straw on sites where plant establishment is the objective. Even where erosion control is the objective, they may not be cost effective. There are several reasons for this. To be effective, the material should have good soil contact. Erosion control blankets are spread over the surface like a blanket and pinned with long staples. The surface needs to be smooth for good contact. If not, the blanket webs over the rough spots and erosion occurs beneath the blanket. This erosion is a very common problem and can be difficult to correct. The smooth surface necessary for good blanket contact gives away the great benefit of roughened or furrowed site preparation previously discussed. Also, many desert species have seedlings that grow as rosettes close to the ground. Most require full sunlight. The webbing shades the seedlings, causing them to grow above their normal ground level and exposing them to drying.

***Dan James**, a revegetation ecologist with training in wildlife biology and natural resources management, is a manager at Western Sere, a company specializing in revegetation of disturbed sites in the Sonoran Desert of North America. He has worked in this field for 12 years. Write to him at P.O. Box 1062, Casa Grande, Arizona 85222 USA.*

Tree Legumes for Reforestation and Afforestation of Arid and Semiarid Lands

Matthew B. Johnson

Approximately one-third of Earth's land area is classified as arid or semiarid, and this area is expanding. Growing human populations have resulted in increased pressures on these lands. The effects of overgrazing, the use of inappropriate agricultural practices, cutting of trees for fuel and other needs, and other exploitive land uses have led to extensive desertification, often with tragic consequences for the people living in these regions. Desertification is a serious problem not only in many developing nations, but also in industrialized countries such as the United States and Australia. The causes and results of desertification are well documented.

Protecting the vegetation of dry regions has received little notice compared with the attention focused on the preservation of wet tropical forests in recent years, yet less than 2 percent of the Central American tropical dry forests remain (Janzen 1988). Many arid and semiarid regions supporting vegetation that can be classified into categories including tropical dry forest, thornscrub, savannah, and desertscrub have been seriously altered by human activity. The ecology of some of these areas is fragile and slow to recover from severe abuse. Valuable germplasm is lost as plants are destroyed. A process termed negative artificial selection often occurs, whereby those plants that are the largest or of highest quality tend to be used up first, eventually resulting in a population of a species with little value (Burkart 1976:522, Aronson 1990:68).

The need for reforestation and afforestation is of major importance in dozens of countries containing arid lands. Steps to halt the process of desertification through protecting the remaining vegetation and soil must be taken. Management plans involving input from local peoples and incorporating appropriate technologies to restore the land to a productive condition and to manage it for sustained use must be implemented. The broad scope of management plans can involve watershed management, erosion control, development of agroforestry and silvopastoral systems, and the establishment or restoration of wildlife habitat. Developing arid lands forestry projects that provide for multiple uses while conserving natural resources offers the greatest potential for long term benefit. A summary of purposes, objectives, and needs involved in arid lands forestry, a relatively new science, is presented by Salem (1985). Weber (1977) offers a thorough account of the technical aspects of arid lands forestry.

Tree Selection in Arid Lands Forestry

The selection of trees for planting on arid lands should incorporate several considerations:

(1) Species should be preadapted to the local environment. Where possible, indigenous species should be used in preference to exotic species. Species should tolerate the temperature extremes and soils of the area where they are to be grown and should be able to survive and grow on natural rainfall, although water harvesting systems may help to augment rainfall.

(2) Newly planted trees require protection from livestock, wildlife, fire, and people.

(3) Potential uses or products from the trees should be determined.

(4) Planting several species generally is more desirable than planting a single species over a wide area.

(5) The potential of exotic species to become aggressive weeds should be considered.

Many species of tree legumes are well suited for forestry projects in arid and semiarid tropical and subtropical regions. The Legume Family (*Leguminosae*) is the third largest plant family. It includes more than 18,000 species in approximately 700 genera. Legumes are diverse in the dry tropics and subtropics. Woody species often are dominant plants in areas where they occur and many can exist on limited water. They are important for local peoples in many countries. These plants provide food, fodder and forage for livestock, fuelwood and charcoal, lumber, shade for people and their livestock, as well as some crops, windbreaks and shelterbelts, medicines, industrial materials, soil stabilization and improvement, wildlife habitat, and landscape plants. Some species are tolerant of saline soils. The ability of many legumes to fix atmospheric nitrogen is a valuable attribute, allowing them to grow in soils with low fertility.

Recommended Tree Legumes

ACACIAS

Acacia is the second largest genus of Leguminosae, with more than 1,000 species. Many acacias are used in forestry programs in dry regions and others have potential for development.

A. *albida* (=*Faidherbia albida*), applering acacia, is widespread from the Sahel to southern Africa. This massive, long-lived tree is unusual in that it becomes deciduous during the rainy season, allowing crops to grow beneath the canopy, where the leaf litter fertilizes the soil. The leaves provide fodder for animals during the dry season. Large quantities of nutritious pods, which ripen at the end of the dry season, are an important source of fodder. The trees generally grow in areas that receive more than 650 mm of annual rainfall, but they will grow in areas with as little as 300 mm if deep soil moisture is available. (Hocking 1987, NAS 1979).

A. *aneura*, mulga, is widely distributed in the drier regions of Australia. It grows well on 200-500 mm of rainfall per year. The foliage of this evergreen tree provides welcome shade and is an excellent fodder if combined with other forage. The wood is durable and very hard. It is used for light construction and for fuelwood and charcoal. (NAS 1979, Turnbull 1990).

A. *cambagei*, stinking wattle, is a widespread native of dry parts of Australia. This evergreen tree grows in areas averaging 125-500 mm of annual precipitation. The wood is reported to be one of the hardest woods in the world. It is valued for its durability and produces an intense heat when burned. (NAS 1980).

A. *caven* is native to southern South America. It occurs in a variety of habitats, including desert. The plants are potentially weedy and frequently colonize disturbed sites but are considered valuable in silvopastoral systems and as a source of quality fuelwood. (Aronson 1990).

A. *nilotica*, Egyptian thorn, is distributed from Africa to India and Pakistan. This variable species is adapted to a wide variety of sites. The trees will grow under very arid conditions but thrive in moist habitats. A. *nilotica* is an important source of fuelwood and charcoal, and is used for making numerous wooden articles. The leaves and pods are an important source of fodder for livestock. Tannin from the bark and pods is used in tanning leather. The trees are the source of some of the gum sold as gum arabic. (NAS 1980).

A. *pendula*, weeping myall, is another of the many Australian acacias. It grows in areas receiving 450-600 mm annual precipitation. The foliage provides high quality fodder. The wood is excellent for fuel. Weeping myall is evergreen, providing shade, and is suitable for windbreaks. (NAS 1979).

A. *saligna*, golden wreath wattle, is native to southwestern Australia. This fast-growing, small, shrubby, evergreen tree is adapted to grow in regions receiving 250-1,000 mm of rainfall annually. Leaves of A. sal*igna* are used for fodder. The wood is brittle and is of low quality for fuel. Gum from the stems may be useful in the food industry. Golden wreath wattle has been used very successfully in stabilizing sand dunes and can be planted for windbreaks. (NAS 1980).

A. *senegal* is the source of gum arabic, widely used in the food industry. This species is found over much of Africa and parts of southwest Asia. It can grow in areas receiving as little as 100 mm of yearly precipitation. Livestock and wildlife browse the leaves and pods. The wood is used for fuel and some construction. A. *senegal* is planted for gum production and is useful for dune stabilization. (Cossalter 1991, NAS 1979, NAS 1980).

A. *seyal* is found from the Sahel to Egypt and southern Africa in areas receiving at least 350 mm of yearly rainfall. The leaves, pods, and flowers are an important source of fodder. The trees are the source of quality timber and are valued for fuelwood. A. *seyal* is tapped for a commercial gum. (NAS 1979, NAS 1980).

A. *tortilis*, the umbrella thorn, is one of the most drought-tolerant trees of Africa and the Middle East. At least one subspecies survives in areas with less than 100 mm of annual rainfall, but others grow in areas with more than 1,000 mm. It produces abundant pods, which are eaten by livestock and wildlife. It provides superior fuelwood and charcoal, and is used for lumber. A. *tortilis* is valuable in silvopastoral systems. Honey, medicines, and other products are derived from this tree by local peoples. The trees are suited for soil stabilization and reforestation on arid sites. (Fagg 1991, NAS 1979, NAS 1980).

Thomson (1989) briefly discusses many species of Australian acacias that are being investigated for arid lands forestry applications.

ALBIZIA

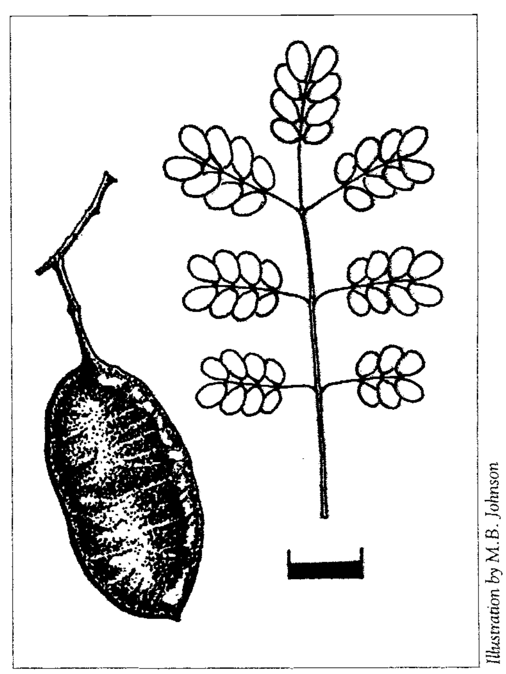
The genus *Albizia* contains several species with forestry potential in semiarid lands. *Albizia lebbeck* is an attractive, large tree from southern Asia that grows in a range of climates. It can grow with as little as 500 mm of rain per year. The leaves provide a nutritious fodder. The wood provides high quality lumber and fuel. It appears to be suited for reforestation on relatively dry, alkaline sites, and has potential in silvopastoral systems. (NAS 1979, N.A.S 1980, Prinsen 1988).

CAESALPINIA

Caesalpinia paraguariensis, guayacán, is a striking tree from southern South America. It grows in areas that receive 375-1,400 mm of annual rainfall. Guayacán is one of the most valuable trees for charcoal production in areas where it grows. The wood is very resistant to decay and is used in construction and the manufacture of some wooden articles. It often is left standing in pastures.

CERATONIA

Ceratonia siliqua, carob or St. John's bread, is native to the eastern Mediterranean region. These beautiful trees are



Caesalpinia paraguariensis (*D. Parodi*) *Burkart, guayacán* adaptable and provide a variety of products. The pods have a high sugar content and are an important food item for people and animals. Gum derived from the seeds is important in the food industry and other commercial applications. The wood of carob is suitable for fuel. The plants are useful for shade, shelterbelts, and erosion control. Carob has potential for widespread planting in semiarid subtropical regions. (NAS 1979).

COLOPHOSPERMUM

Colophospermum mopane, mopane, is a distinctive tree from southern Africa, where it sometimes forms pure woodlands. It occurs in areas that receive 200-850 mm of yearly rainfall. The plants tolerate some salinity and are useful in soil stabilization. The very hard, durable wood is difficult to cut but is useful in construction and provides an excellent fuelwood. The leaves of mopane are a nutritious fodder for livestock and wildlife. (NAS 1980).

GEOFFROEA

Geoffroea decorticans, chañar, is native to southern South America. This small, spiny tree with green, photosynthetic bark is well adapted to a variety of sites in semiarid climates. It tolerates some freezing and is drought resistant. Chañar is unusual among legumes, in that it produces drupes rather than pods. The fleshy pulp of these fruits is widely eaten by livestock and wildlife, and is suitable for human consumption. This species awaits development as a possible tree food crop. (Aronson 1990).

GLEDITSIA

Gleditsia triacanthos, honey locust, is a large tree native to the eastern United States, but it is well adapted to a wide range of climatic conditions and soils. The tree tolerates cold winters with temperatures well below freezing and will grow in hot, semiarid subtropical regions. The plants are fast growing with adequate irrigation and are drought-resistant when established. The large, abundantly produced, sweet pods are eaten by livestock and humans. The leaves are used for fodder. (NAS 1979).

LEUCAENA

The genus *Leucaena* contains several species used in agroforestry.

L. leucocephala, a frost-tender species native to southern Mexico, is widely planted in the tropics for wood, shade fodder, and green manure. It also is used for soil stabilization and to provide shade for some crops. Although best adapted to humid climates, *L. leucocephala* can grow well in semiarid regions. The rapid growth rate and vigorous coppicing make it worth considering for some situations where the potential to become weedy is not a problem.

L. greggii, *L. retusa*, and other species from semiarid regions are in need of investigation.

OLNEYA

Olneya tesota, desert ironwood, is a small, spiny tree native to the Sonoran Desert of southwestern North America. This species grows in regions that receive 100-300 mm of yearly rainfall. The slow-growing trees produce a dense wood that will not float when fresh. The wood is valued for wood carvings and produces excellent charcoal. It is highly resistant to decay. The seeds of desert ironwood are edible, with a flavor similar to that of soybeans. *Olneya* should be evaluated for potential as a tree food crop for hot, arid climate.

PARKINSONIA

Parkinsonia aculeata is known under a variety of names, including Mexican palo verde and Jerusalem thorn. It is native to the Americas and has become widely naturalized. The trees are drought-resistant and tolerate saline conditions as well as some winter freezing. Growth rates can be fast; plants resprout vigorously after cutting. The wood is suitable for fuel and charcoal. The foliage and pods have some fodder value. (NAS 1980).

PROSOPIS

The genus *Prosopis* contains many species that are valuable dry land forestry trees. The center of diversity for the genus is southern South America, with fewer species native to North America and several native to parts of Africa and southwest Asia.

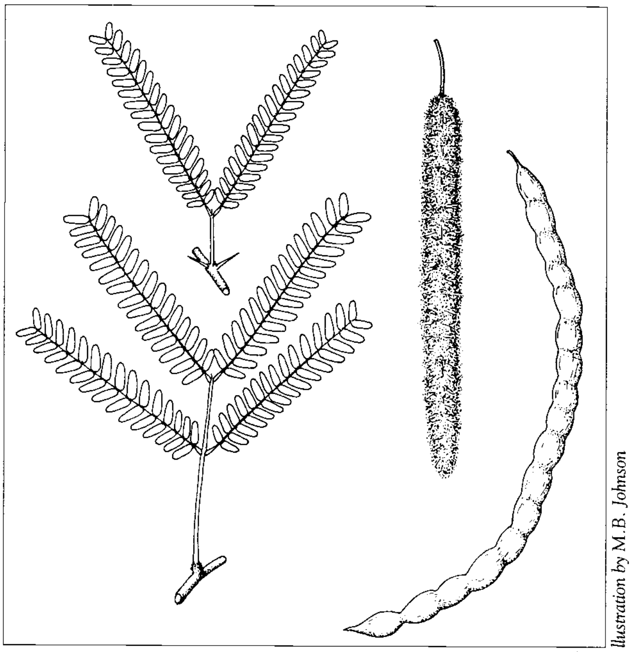
Although *Prosopis* species have the potential to become serious weeds under some conditions, these outstanding plants are important in many areas, providing shade, very high quality fuelwood and charcoal, durable wood for construction and wooden articles, fodder from the leaves and pods, wildlife habitat, honey, and food for people from the ground pods. Felger (1990) offers an excellent discussion of the potential for developing *Prosopis* as a major world food crop in arid regions.

Several species with low water requirements are useful for soil stabilization, reforestation, and afforestation in arid environments. Others are tolerant of high salinity. Other local products from these trees include medicines and gums.

Prosopis species can be highly variable in growth form, degree of spininess, and fodder quality. They are useful plants in silvopastoral systems, where the fallen leaves improve soil quality for grasses and where livestock can take advantage of the shade. Some plants grow in areas that receive as little as 100 mm of rain annually. Some species are not resistant to freezing, but others will survive temperatures well below freezing for limited periods.

P. alba, *P. chilensis*, and *P. nigra* are among the species called algarrobo in South America. These species are highly valued for many uses, including shade, lumber, fuelwood and charcoal, fodder from the pods and leaves. These drought-resistant trees can attain growth rates of 2 m per year with adequate moisture. These species, and *P. alba* in particular, are among the trees with the greatest potential for forestry programs in arid and semiarid regions. (Aronson 1990, Burkart 1976, NAS 1979, NAS 1980)

P. glandulosa, *P. laevigata*, and *P. velutina*, all from southwestern North America, commonly are called mesquite. They are considered range pests in some areas, but they



Prosopis velutina *Wooton, velvet mesquite*

provide valuable fuelwood and charcoal, nutritious pods, honey, and shade. (Burkart 1976).

P. cineraria, kejari, from India and parts of the Middle East, is a valuable source of fodder and fuel. It often is left standing in fields, where crops growing beneath it are fertilized by the fallen leaves. The trees are drought-resistant, surviving on as little as 75 mm of rain per year. Kejari is suitable for use in stabilizing sand dunes and other arid sites, and is reported to tolerate alkaline soils. (Burkart 1976, NAS 1980, Sandison and Harris 1991).

P. juliflora is native from central Mexico to northern South America. It is widely naturalized in India and parts of Africa, sometimes becoming a serious weed. The foliage and pods of many plants apparently are not highly palatable for fodder or food (Felger 1990). The plants are an important source of fuel and are useful for soil stabilization. This species will grow in areas receiving 150 mm of annual rainfall and is reported to be somewhat salt-tolerant. (Burkart 1976, Felker et. al. 1981).

P. pallida, a frost-sensitive species from dry, coastal regions of Peru, Ecuador, and Columbia, has become widely naturalized in the past century. It is tolerant of high salinity (Felker et al. 1981) and is well suited for planting in coastal areas, although it requires more moisture than some other *Prosopis* species. The trees are valued for shade, fuel, timber, and forage from the pods and leaves. (Brewbaker 1987, Burkart 1976, Felker et al. 1981, NAS 1979, NAS 1980)

P. tamarugo, tamarugo, is endemic to northern Chile. It occurs naturally in a salt desert called the Pampa de Tamarugal. A large area of this rainless region is covered with a crust of salt nearly a meter thick. The trees receive moisture from underground water in habitat. This species has been shown to survive and grow slightly under laboratory conditions when irrigated with NaCl solution at slightly above the salt concentration of sea water (Felker et al. 1981). A forestry program in Chile has planted an area of about 35,000 ha to tamarugo. This tree has excellent potential for afforestation of arid, saline areas but it has a slower growth rate than many other *Prosopis* species. (Aronson 1990, Burkart 1976, Felker et al. 1981, NAS 1980).

Other useful species include *P. africana* and *P. caladenia*.

TAMARINDUS

Tamarindus indica is the well known tamarind. A native of dry tropical Africa, the tamarind has been widely introduced. The trees are adaptable to a variety of sites. They are drought-resistant and seldom are damaged by strong winds. The fruits of tamarind have a wide variety of food uses. The trees require prolonged dry periods to produce large quantities of fruit. The leaves, flowers, and immature pods can be used in cooking. Tamarind wood is of high quality for wooden articles and is an excellent fuel. The plants are slow-growing and sensitive to frost. Tamarind deserves wider planting in semiarid tropical regions. (NAS 1979).

OTHER GENERA

Numerous other arborescent legumes have considerable potential for use in arid lands forestry. Among these plants are species in the genera *Bauhinia*, *Cassia*, *Dichrostachys*, *Entada*, *Erythrina*, *Eysenhardtia*, *Haematoxylon*, *Lysiloma*, *Parkia*, *Piliostigma*, *Pithecellobium*, *Pterocarpus*, and *Senna*. Many are used by local peoples in areas where they naturally occur. Evaluations could lead to these species gaining wider use. In addition to trees, many shrubby legumes also are suited for forestry projects in dry lands.

The Bottom Line

Reforestation and afforestation of arid and semiarid lands is of vital necessity, and arid-adapted leguminous plants can play a major role in achieving this goal. The success or failure of efforts to halt continued desertification will have global repercussions. Coordinated efforts are needed to implement effective forestry programs, while helping peoples in arid regions to achieve self-sufficiency. These efforts, together with progress in limiting human population growth, may serve to halt or reverse desertification while improving the quality of human life.

References

Aronson, J. 1990. Desert plants of use and charm from northern Chile. *Desert Plants* 10(2):65-74, 79-86.

Brewbaker, J. L. 1987. *Prosopis pallida*: pioneer species for dry, saline shores. NFT Highlights, *NFTA* 87-05.

Burkart, A. 1976. A monograph of the genus *Prosopis* (Leguminosae subfamily Mimosoideae). *Journal of the Arnold Arboretum* 57(3):219-49; 57(4):450-525.

Cossalter, C. 1991. *Acacia senegal*: gum tree with promise for agroforestry. NFT Highlights, *NFTA* 91-02.

Fagg, C. 1991. *Acacia tortilis*: fodder tree for desert sands. NFT Highlights, *NFTA* 91.

Felger, R. S. 1990. Mesquite: a world food crop. *Aridus* 2(1):1-3.

Felker P., P. R. Clark, A. E. Lang, and P. F. Pratt. 1981. Salinity tolerance of the tree legumes: Mesquite (*Prosopis glandulosa* var. *torreyana*, *P. velutina*, and *P. articulata*), algarrobo (*P. chilensis*), kiawe (*P. pallida*) and tamarugo (*P. tamarugo*) grown in sand culture on nitrogen-free media. *Plant and Soil* 61:311-17.

Hocking, D. 1987. *Faidherbia albida*: the farmers' choice for semi-arid and arid zones. NFT Highlights, *NFTA* 87-02.

Janzen, D. H. 1988. Tropical dry forests: the most endangered major tropical ecosystem. In E. O. Wilson and F. M. Peter (eds.), *Biodiversity*. Washington, DC: National Academy Press.

National Academy of Sciences (NAS). 1979. *Tropical legumes: resources for the future*. Washington, DC: National Academy of Sciences.

—. 1980. *Firewood crops: shrub and tree species for energy production*. Washington, DC: National Academy of Sciences.

Prinsen, J. H. 1988. *Albizia lebbeck*: a promising fodder tree for semi-arid regions. NFT Highlights, *NFTA* 88-03.

Salem, B. B. 1985. A strategy on the role of forestry in combating desertification. In E.E. Whitehead, C.F. Hutchinson, B.N. Timmermann, and R.G. Varady (eds.), *Arid lands today and tomorrow: proceedings of an international research and development conference, Tucson, Arizona, October 20-25, 1985*. Boulder, CO: Westview Press, in cooperation with the Office of Arid Lands Studies, University of Arizona.

Sandison, M. S. and P. J. C. Harris. 1991. *Prosopis cineraria*: a multipurpose tree for arid areas. NFT Highlights, *NFTA* 91-04.

Thomson, L. 1989. Acacias for the hot dry subtropics. NFT Highlights, *NFTA* 89-02.

Turnbull, J. W. 1990. *Acacia aneura*: a desert fodder tree. NFT Highlights, *NFTA* 90-03.

Weber, F. R. 1977. Reforestation in arid lands. *Volunteers in Technical Assistance (VITA) Publications Manual Series* 37E.

***Matthew Johnson** received his M.S. in horticulture in 1988. He has been employed as plant explorer and botanist for the Desert Legume Program (DELEP), a cooperative project of the Boyce Thompson Southwestern Arboretum and the University of Arizona College of Agriculture, since 1989. He is a botanical illustrator and the author of several articles on the horticulture and botany of arid lands plants.*

News

Australian Arid Lands Botanic Garden Development Proceeds Apace

John R. Zwar reports from Port Augusta, South Australia, that the Australian Arid Lands Botanic Garden there has moved considerably closer to reality since he first publicly proposed the idea in 1981.

The garden, which is being developed on 300 ha of Crown Land at Port Augusta West, will feature arid land plants from throughout Australia. Among its primary missions will be education, including an advisory and extension service for residents, communities, and developers. The garden will display, demonstrate, and use technology appropriate to arid Australia, including solar and wind power, water harvesting and conservation techniques, desalination technology, and appropriate building design. Its developers, who expect the garden to attract tourists to the city and thereby to benefit the local economy, also propose to exchange and sell information, plant material, and seeds worldwide.

Support for the garden's development has come from the nonprofit Friends of the Australian Arid Lands Botanic Garden, Port Augusta, Inc.; the government of South Australia; the Port Augusta City Council; and the Electricity Trust of South Australia. Early stages of garden development included site clean-up, construction of rabbit-proof boundary fencing, laying water pipe, establishment of a nursery plantation, and preliminary tree establishment trials.

The Western Mining Corporation came on board as a corporate sponsor in 1989 with a grant for preparation of site contour maps and a detailed survey of the site's existing flora. Botanists from the Botanic Gardens of Adelaide began work on this two- to three-year project in 1990, the same year the corporation enlarged its role by agreeing to fund preparation of a master plan for the garden. Grant Henderson, a landscape architect who lectures at the University of Canberra, began work on the plan in January 1991 with six months of on-site research. He is expected to deliver the completed plan early this year.

Henderson's recommendations are expected to include: that the garden grow only plants native to Australia; that buildings be regionally appropriate and constructed of rammed earth; that planting zones within the park be developed to demonstrate the interrelationships among plants and other environmental factors; that a large walk-through aviary divided into areas featuring both vegetation types and the birds associated with them be included.

It is estimated that full development of the garden will require 15 years and approximately A$9 million to A$12 million. Zwar asks that any individuals or institutions interested in supporting continued progress on the garden direct inquiries to:

John Zwar O.A.M. Vice President & Acting Secretary
Friends of the Australian Arid Lands Botanic Garden
P.O. Box 2040
Port Augusta, SOUTH AUSTRALIA 5700

Ground Broken for Desert House at Desert Botanical Garden

Ground was broken November 6, 1991, at Desert Botanical Garden in Phoenix, Arizona, for Desert House, a model demonstration project of residential water conservation and energy efficiency designed to be of interest to the general public, home builders, developers, and government planners and policy makers.

Desert House will show that water- and energy-efficient features can be incorporated economically and aesthetically into single-family homes without reducing either sales appeal or residents' quality of life. Commercially practical concepts, methods, materials, and equipment will be employed in construction and operation of the house and its xeriscape landscaping. An adjacent information center will explain the house's goals and design features to visitors and, with the help of user-friendly computers, urge visitors to explore ways to save water and energy in their own homes.

Plans for Desert House incorporate and build on the results of research conducted by the Office of Arid Lands Studies at Casa del Agua in Tucson, an existing home that was retrofitted for maximum water and energy efficiency. OALS's partners in the Desert House project include the City of Phoenix, the Salt River Project, Desert Botanical Garden, the Valley Partnership, and The University of Arizona College of Architecture.

For information about the Desert Botanical Garden and its programs, write:

Desert Botanical Garden
1201 N. Galvin Pkwy.
Phoenix, AZ 85008 USA

Kennith E. Foster (left), Director of the Office of Arid Lands Studies, talks with Fred S. Matter (center), Assistant Dean of the UA College of Architecture, and Yair Etzion, Head of the Desert Architecture Unit at Ben-Gurion University of the Negev, at groundbreaking ceremonies for Desert House.

Update from the Royal Botanic Gardens, Kew

The Garden's Survey of Economic Plants for Arid and Semi-Arid Lands (SEPASAL), begun in 1981 as a compilation of plants adapted to growing naturally under drought and other adverse conditions and with potential for providing food, fuel, fodder and other economic benefits, continues. The SEPASAL database is used to target useful wild species in germplasm collections by Kew Seed Bank collectors and others working in Australia, Botswana, Brazil, Mexico, North Africa, and elsewhere. Currently under study are economic grasses in various arid regions and wild vegetables in Zimbabwe. Information for addition to the SEPASAL databases is being collated on land restoration plants and species of economic potential for northeast Brazil.

The Garden's Economic and Conservation Section (ECOS), of which SEPASAL is a part, continues to build its database on the medicinal and poisonous properties of plants from around the world. The information is used, among other things, to answer questions and requests for information from researchers and medical and horticultural professionals both in the United Kingdom and abroad. News of medicinal and poisonous plant research and observations from interested parties anywhere in the world are welcome.

Laura Hastings of ECOS and Rob Nash of the Biochemistry Section of Jodrell Laboratories are leading an investigation into the antidiabetic properties of plants (see also *Arid Lands Newsletter* 31, Fall/Winter 1991). They have thus far identified seven plants worthy of investigation; extracts of these have been made at Kew and sent to collaborators for trial.

The Garden's Frances Cook is seeking information on projects in which trees or other plants are being used to help control erosion and to improve the soil in arid and semiarid regions of the world. He is interested particularly in: species used; uses to which species are put; their location on site; study area's climate, hydrology, and topography; project's duration; procedures for species selection; methods of cultivation and management; organization of labor; and evaluation of species suitability. A more detailed questionnaire is available for those who would find it helpful.

ECOS already has data on hundreds of species useful in erosion control, land restoration, or soil improvement, and this information is available to researchers and land managers. When requesting information or advice, include site details (location, climate, altitude, soils, topography), the nature of the problem under study, and a list of species already tried and their shortcomings.

Interested parties may write to the Garden's researchers and staff at:

Royal Botanic Gardens, Kew
Richmond, Surrey
TW9 3AB, England, UNITED KINGDOM

OALS Scientist Launches Multinational Research Project

Barbara Timmermann, Associate Professor of Arid Lands Resource Sciences and of Pharmaceutical Sciences at The University of Arizona, has been awarded a $45,000-grant by the Institute of Physical and Chemical Research (RIKEN), Tokyo, Japan, for a multinational research venture designed to derive new drugs and environmentally safe pesticides from the medicinal plants of central Chile. Among the properties she and her colleagues will be seeking in plant sources are anti-tumor, anti-HIV, and anti-hypertensive actions.Under the terms of the grant, Dr. Timmermann's colleagues in Chile will identify and collect plants, she will run the chemical analyses of those plants at The University of Arizona, and her colleagues in Japan will conduct biological testing.

Dr. Barbara N. Timmermann

The project, entitled "Bioregulators for Medicinal and Agrichemical Applications Based on Natural Products from Plants of Chile," grew out of Dr. Timmermann's long-term collaboration with colleagues in both South America and Japan. In 1973, she co-authored, with Hirosuke Yoshioka and Tom Mabrey, *Sesquiterpene Lactones: Chemistry, Nuclear Magnetic Resonance, and Plant Distribution* (University of Tokyo Press), which has since become a standard reference in the field.

Dr. Timmermann will travel to Japan this spring to deliver a round of lectures at universities and privately funded research laboratories around the country. In October, she will travel to Brazil in conjunction with a $50,000-grant she has received from the MacArthur Foundation to activate a network of research institutions in the Caatinga of Brazil, the Argentine Gran Chaco, and the Norte Chico of Chile.

The October meeting will be the first step toward establishing a South American arid lands center modeled on The University of Arizona's Office of Arid Lands Studies.

Lentil Derived From Egyptian Germplasm Debuts in U.S.

The crimson lentil (*Lens culinaris* Medikus), a new cultivar derived from the "purified landrace" Giza-9, has been approved for release in the western U.S.

The new cultivar is being touted for its adaptability to low rainfall, its early blooming date, its tall and upright growth habit, and its good yield. Its first two properties, in particular, should make it a likely candidate for use in arid and semiarid regions worldwide.

Lentil probably is one of the first pulse crops to be domesticated in the Fertile Crescent of the Middle East. Carbonized lentil remains from Tel Mureybit on the banks of the Euphrates River in northern Syria date back about 10,000 years.

The Egyptian Giza-9 germplasm from which the crimson lentil was derived was supplied to scientists at the University of Washington by the International Center for Agricultural Research in the Dry Areas (ICARDA). The organization's gene bank holds nearly 100,000 samples of wheat, barley, legume, and pasture crops from around the world. To contact ICARDA researchers, write:

ICARDA
P.O. Box 5466
Aleppo, SYRIA

Seminar

1992 International Seminar on Forest Administration and Management

University of Michigan
Ann Arbor, Michigan USA
September 13-October 6, 1992

Conducted by USDA Forest Service and School of Natural Resources, University of Michigan.

The ninth annual seminar will begin at the University of Michigan, travel to National Forests and related industrial sites in Michigan, Wisconsin, and New Mexico, and finish with visits to international institutions in Washington DC. Its primary themes will be the international significance of forest resources and how different nations approach resource management problems; policy development, employing a case study approach and with special emphasis on conflict management; comparison of administrative practices among private business, federal, state, and local governments, and educational institutions; the multiple use land management philosophy; an issue-oriented study of the challenges of conserving biological diversity while meeting human demands for forest products; and research, extension, and technology transfer.

The seminar, to be taught jointly by the University and the Forest Service, will be limited to 32 participants, with special emphasis on participants from developing nations. Women are especially encouraged to apply. The seminar will be conducted in English only.

Seminar expenses: Fees covering registration, tuition, instructional materials, meals, lodging, and in-country seminar travel total US$4,600. Travel costs to and from the seminar (arriving Detroit, Michigan, and departing Washington DC) are additional.

Applications must be received by July 1, 1992. For an application or information, contact:

Director
International Forestry Seminars
School of Natural Resources
University of Michigan
Ann Arbor, MI 48109-1115 USA

Telephone: 313-747-4337
Telex: 4320815 UOFM/UI
FAX: 313-936-2195

CONFERENCE

FOURTH INTERNATIONAL CONFERENCE ON DESERT DEVELOPMENT: SUSTAINABLE DEVELOPMENT FOR OUR COMMON FUTURE

Mexico City, Mexico
July 25-30, 1993

The conference is organized by the International Desert Development Commission (IDDC) and hosted by the Graduate College, Montecillo, Edo. de Mexico.

Plenary sessions, lectures, technical and scientific working groups, poster sessions, exhibitions, and post-conference technical tours will concentrate on the following topics: (1) soil and water conservation; (2) irrigation and water management; (3) watershed management; (4) salt-tolerant plants; (5) alternative energy sources; (6) socioeconomic issues in arid lands; (7) ecology of arid lands; (8) forestry and agroforestry; (9) animal production; (10) dry land crops; (11) agrochemicals and pollution control; (12) conservation of natural resources and recycling.

Official languages of the conference will be English and Spanish, but papers are to be in English. Abstracts are due September 1, 1992; successful authors will be notified by December 1, and finished manuscripts are due April 25, 1993.

For details on the conference and accommodations, write:
Dr. Manuel Anaya Garduño
Executive Secretary, Scientific Committee IV ICDD
Colegio de Postgraduados
Monticello, Edo. de Mexico 56230 MEXICO
FAX: ++(52) 595-45723

PUBLICATIONS

MAP

World Map of the Status of Human-Induced Soil Degradation. 1990. The International Soil Reference and Information Centre (ISRIC), P.O. Box 353, 6700 AJ Wageningen, The Netherlands. US$25 (US$20 unfolded).

Published by ISRIC for the United Nations Environment Programme, in cooperation with Winand Staring Centre, International Society of Soil Science, Food and Agriculture Organization of the United Nations, and International Institute for Aerospace Survey and Earth Sciences, this full-color map comes in three sheets (Mercator Projection, variable scale ranging from 0°=1:15,000,000 to 72°=1:4,650,000): 1—North and South America; 2—Europe, Africa, and Western Asia; 3—Eastern Asia and Australia. The map identifies areas of low, medium, high, and very high degradation, color-coded for type: water erosion, wind erosion, chemical deterioration, and physical deterioration. Letter codes identify the kinds of degradation within each type, primary causative factors, recent past rate of degradation, and off-site effect. All keys are explained in English, Spanish, and French. Included with the map is a 30-page *Explanatory Note* by L.R. Oldemann, R.T.A. Hakkeling, and W.G. Sombroek.

REPORT

Arid Ecosystem Interactions: Recommendations for Drylands Research in the Global Change Program. 1991. Available by contacting: Diane Ehret, Office for Interdisciplinary Earth Studies (OIES), University Corporation for Atmospheric Research, P.O. Box 3000, Boulder CO 80307-3000 USA.

The report is based on a workshop attended by about 40 researchers in the physical and social sciences in October of 1989. The first half of the report describes current scientific problems in arid and semiarid regions; the second recommends priorities for research and monitoring projects designed to be of use to scientists and policy makers.

BOOKS

Hydrological Basis of Ecologically Sound Management of Soil and Groundwater. 1991. Edited by H.P. Nachtnebel and K. Kovar. International Association of Hydrological Sciences (IAHS) Press, Institute of Hydrology, Wallingford, Oxfordshire OX10 8BB, UK (US orders to: Office of the Treasurer IAHS, 2000 Florida Avenue NW, Washington, DC 20009 USA). US$55.

This volume collects 36 selected papers from one of six symposia conducted during the XXth General Assembly of the International Union of Geodesy and Geophysics at Vienna in August 1991. The symposium's purpose was to present state-of-the-art methodologies for ecologically sound management of soil and groundwater, with particular emphasis on the relationships between hydrological changes in the soil and groundwater system and their effects on ecosystems. Papers are arranged under four headings: modelling of water flow and contaminant transport in saturated and unsaturated zones in relation to ecology; physical and hydrochemical processes, especially the dynamic aspects, in interface zones, and their implications for ecology; methodology for the identification of hydrologic and biotic parameters, and the design, operation, and applicability of field monitoring networks; case studies in ecologically sound management under various land use practices (preservation of wetlands, forestry, agriculture, etc.).

Geraghty & Miller's Groundwater Bibliography. 1991. Compiled and edited by Frits van der Leeden. 507 pp. Water Information Center Inc., 125 E. Bethpage Rd., Plainview, NY 11803 USA. US$69.95 (paper).

The fifth edition of this bibliography contains some 5,600 references, up from 1,500 references in the first edition (1971). Entries are arranged in two parts: a General Section, including general bibliographies, periodicals, and books, and a Subject Section, including publications on 31 topics ranging from groundwater contamination to water witching. Extended contents listing; author index.

The Ecology of Desert Communities. 1991. Edited by Gary A. Polis. 450 pp. The University of Arizona Press, 1230 N. Park Ave. #102, Tucson, AZ 85719 USA. US$49.95 (cloth).

Drawing on data from deserts around the world, 14 authors here synthesize findings on the community ecology of four main groups: plants, soil biota, vertebrates, and arthropods, with the last receiving the attention due a group whose biomass and species diversity are greater than that of all other desert animals combined. Overall, the authors concentrate on experimental and holistic analyses of the patterns and processes that influence the distribution and abundance of individual species and groups of species.

Minding the Carbon Store: Weighing U.S. Forestry Strategies to Slow Global Warming. 1991. By Mark Trexler. World Resources Institute Publications, P.O. Box 4852, Hampden Station, Baltimore, MD 21211 USA. US$12.50.

Scientists long have known that trees remove carbon dioxide from the atmosphere as they grow. In this volume, the author offers specific recommendations to offset carbon dioxide emissions from fossil fuel combustion, including promoting urban tree planting, creating a forestry reserve program on economically marginal crop and pasture lands, and expanding biomass-to-energy demonstration programs to evaluate the technological, environmental, and economic feasibility of potential fossil fuel replacements. "While tree planting can help moderate net carbon emissions," Dr. Trexler cautions, "it is not a substitute for a U.S. energy policy that addresses the problem of global warming," including new emphasis on reducing emissions from fossil fuels.

Cornucopia: A Source Book of Edible Plants. 1991. By Stephen Facciola. 677 pp. Kampong Publications, 1870 Sunrise Dr., Vista, CA 92084 USA. US$35 (plus postage).

Facciola's self-published volume describes and identifies sources for 3,000 species and 7,000 cultivars of food plants from around the world. Included are heirloom vegetables; herbs and spices; fruits, nuts, and berries; grains; edible flowers; edible wildings; sprouting seeds; mushroom spawn, and starter cultures. Sources (1,300 addresses) are provided both for seeds and for nursery stock, as well as for specialty produce and food products.

SERIES

Desert Accents. 1992. For price and ordering information, contact the publisher: Arizona Native Plant Society, P.O. Box 41206 Sun Station, Tucson, AZ 85717 USA.

This booklet is the fifth in the Society's Urban Landscape Series. It features 90 desert species suitable for use as accent or focal point plants in residential or commercial xeriscapes. The booklet includes color photos, descriptive information, design notes, instructions for planting and maintenance, and a color-coded table for easy reference.

Three of the earlier booklets in the series—*Desert Shrubs*, *Desert Trees*, and *Desert Ground Covers and Vines*—are available from the Office of Arid Lands Studies, as is the folded poster/brochure *Flowering Periods for Common Desert Plants of Southwestern Arizona*, by William G. McGinnies. All are priced at US$1.50 plus postage: 10 percent of order for US orders, US$0.50 for Canada and Mexico, US$1 for all other countries.

Order from: Publications, Office of Arid Lands Studies, University of Arizona, 845 North Park Avenue, Tucson, AZ 85719 USA

"Lakes of Grass: Regenerating Bourgou in the Inner Delta of the Niger River." No. 2, Spring 1990. 15 pp. **"Reforestation: The Ethiopian Experience, 1984-1989."** No. 4, Spring 1991. 27 pp. Both are titles in the UNSO (United Nations Sudano-Sahelian Office) *Technical Publications Series*. Available by writing to: UNSO, One United Nations Plaza, New York, NY 10017 USA.

UNSO was established in 1973 to assist in the recovery and rehabilitation of the drought-stricken Sudano-Sahelian region of Africa. It recently has begun systematically to publish the results of its experience in this series. In "Lakes of Grass" is reported UNSO's effort to regenerate bourgou (*Echinochloa stagnina*), an aquatic grass of considerable economic importance in central Mali before it fell victim to 17 years of drought (1968-1985). "Reforestation" recounts the organization's efforts to restore another economically (and environmentally) important plant community, this one despoiled by human population pressure in the Horn of Africa. Both publications provide considerable technical detail, but all numbers in the series are intended for a diverse readership, including policy makers, administrators, development workers, researchers, teachers, and the interested public.

Posters

Singing Down Roots: Plant Folklore of the Desert Southwest is a series of six limited edition posters celebrating the plant legacy of the Native American West. The series was created by the Office of Arid Lands Studies and funded, in part, by the Arizona Humanities Council. Each poster, illustrated by Paul Mirocha, is printed in two colors on durable paper and measures 22 inches by 35 inches. Posters are available for US$75.00 per set, plus US$4.50 per set for postage and handling, or for US$15.00 each, plus $1.50 per poster. The posters:

The Mescal Agave Talks Like That. Larry Evers and Felipe Molina, authors of *Yaqui Deer Songs/Maso Bwikam: A Native American Poetry* (The University of Arizona Press), translate and comment on a text selected from the rich Yaqui tradition of songs. Mirocha's drawing is of kuu'u, the mescal agave (*Agave angustifolia*), in bloom.

Yucca baccata: From the Beginning. Mirocha's drawing of 'igaiyé (*Yucca baccata*) illustrates a passage selected from the extensive Western Apache herbal lore and translated by Gayle Potter-Basso, who also contributes a brief essay on this indispensable wilding.

Coyote Ate It and Really Laughed. It was a succulent pad of the prickly pear cactus that made Coyote laugh in this excerpt from the Cocopa tradition, selected and annotated by Leanne Hinton. The Trickster changes his tune in Mirocha's drawing of Coyote with a mouthful of cholla, prickly pear's thorny cousin.

I Am the Ocotillo. Tohono O'odham third-grader Sonya Ortegas's poem sets the tone for teacher Danny Lopez's meditation on melhog, the versatile wilding that Anglo residents of the Sonoran Desert sometimes call buggy whip cactus. Mirocha's drawing of a spike of flowers atop ocotillo's long, thorned, leafless dry season stalk graces the poster.

The Corn Maiden's Song. Emory Sekaquaptewa chose and translated a song for Qa'ökatsina—the Hopi Corn Kachina—as the point of departure for his elucidation of the spiritual nature of corn, the rain that is its due, and the obstacles to the coming of rain that profane humans can call into being. Mirocha interprets the interconnectedness of the plant, the spirit, and the blessing of rain in a dry land with a fanciful montage.

The Tobacco Plant Has a Laugh. Uva—tobacco—is sacred to the Hualapai. As we see in the story of the Frog Girl Hanya' Misi', translated here by Elnora Mapatis and expanded upon by Lucille Watahomigie, the tobacco plant was not always a member of the vegetable kingdom. Mirocha's drawing weaves an intertwined image of the sacred plant's past and present forms.

Visitors

Mme. Hadiza Adamou

Mme. Hadiza Adamou, Director of the Documentation Center at the Institut National de Recherche Agronomique in Niger, last August attended a course in information management at The University of Arizona, dividing her time between the Arid Lands Information Center (ALIC) at OALS and The University of Arizona Libraries. While at ALIC, Mme. Adamou concentrated on a variety of computer technologies, including ALIC and SEL online catalogs and such online databases as AGRIS and Current Contents on Diskette. She holds a degree in librarianship from The University of Benin and hopes to attend graduate library school in the U.S., possibly at The University of Arizona.

Last September, the Office of Arid Lands Studies (OALS) hosted a distinguished delegation from the new University of Saint-Louis in Dakar, Senegal. **Ahmadou Lamine Ndiaye,** Rector of the University; **Ndiawar Sarr,** Dean of the Faculty of Letters and Humanities; **Babacar Kante,** Dean of the Faculty of Law; **Francois Boxe,** Dean of the Faculty of Economics and Management, and **Galaye Dia,** Dean of the Faculty of Applied Mathematics and Computer Sciences, discussed with their American colleagues at the University of Arizona curriculum related to arid lands and explored ways in which the two universities might exchange information and scholars to their mutual benefit.

Hadj Boudissa Safi, Vice President of the Ibn Al Awam Association in Algeria, met with OALS Director Kennith Foster and with Arid Lands Information Center (ALIC) Manager Barbara Hutchinson last October during a month-long tour of the U.S. sponsored by the United States Information Agency (USIA). Ibn Al Awam is a non-governmental organization dedicated to the economic, social, and cultural development of Algeria's semiarid regions. Its activities include sponsoring research, hosting conferences and seminars, and encouraging cooperation among Algerian agencies and international organizations. Mr. Safi gathered information during his visit on sustainable agriculture; water conservation; remote sensing of water resources; agroforestry; biotechnological research in agriculture, and the uses of traditional and natural products, rather than chemicals, to boost agricultural production.